Incorporating Feedback in Travel Forecacting: Methods, Pitfalls, and Common Concerns

March 1996

TMIP

Travel Model Improvement Program

Department of Transportation
Federal Highway Administration
Federal Transit Administration
Office of the Secretary

Environmental Protection Agency

Department of Energy

U.S.Department of Transportation

U.S.Environmental Protection Agency

Travel Model Improvement Program

The Department of Transportation, in Cooperation with the Environmental Protection Agency and the Department of Energy, has embarked on a research program to respond to the requirements of the Clean Air Act Amendments of 1990 and the Intermodal Surface Transportation Efficiency Act of 1991. This program addresses the linkage of transportation to air quality, energy, economic growth, land use and the overall quality of life. The program addresses both analytic tools and the integration of these tools into the planning process to better support decision makers. The program has the following objectives:

1. To increase the ability of existing travel forecasting procedures to respond to emerging issues including: environmental concerns, growth management, and lifestyle along with traditional transportation issues,

2. To redesign the travel forecasting process to reflect changes in behavior, to respond to greater information needs placed on the forecasting process and to take advantage of changes in data collection technology, and

3. To integrate the forecasting techniques into the decision making process, providing better understanding of the effects of transportation improvements and allowing decision makers in state governments, local governments, transit operators, metropolitan planning organizations and environmental agencies the capability of making improved transportation decisions.

This program was funded through the Travel Model Improvement Program.

Further information about the Travel Model Improvement Program may be obtained by writing to

Planning Support Branch (HEP-22)
Federal Highway Administration
U.S. Department of Transportation
400 Seventh Street, SW
Washington, DC 20590

Incorporating Feedback in Travel Forecasting: Methods, Pitfalls and Common Conerns

Final Report
March 1996

Prepared by
COMSIS Corporation
8737 Colesville Road, Suite 1100
Silver Spring, MD 20910-3921

Prepared for
Office of Environment and Planning
Federal Highway Administration
Washington, DC 20590

Sponsored by
US Department of Transportation
Federal Highway Administration
Federal Transit Administration
Office of the Secretary
US Environmental Protection Agency
US Department of Energy

Distributed in Cooperation with
Technology Sharing Program
Research and Special
Programs Administration
US Department of Transportation
Washington, DC 20590

DOT-T-96-14

TABLE OF CONTENTS

SECTION **PAGE**

EXECUTIVE SUMMARY 1

1. OVERVIEW 1.1
   1.1 Project Objectives 1.1
   1.2 Methods of Introducing Feedback 1.4
   1.3 Significant Findings 1.5
   1.4 Topics for Future Research 1.6
   1.5 Report Contents 1.7

2. WHEN AND WHERE SHOULD FEEDBACK BE APPLIED 2.1
   2.1 Factors and Key-Indicators of the Need for Feedback 2.1
   2.2 Feedback Decision Hierarchy 2.10

3. IMPLEMENTATION OF FEEDBACK 3.1
   3.1 What is Feedback and Why do it? 3.1
   3.2 Basic Concepts and Definitions of Feedback. 3.6
      3.2.1 Equilibrium 3.6
      3.2.2 What is an iteration? 3.7
      3.2.3 Convergence 3.8
      3.2.4 What are the "Sub-Problem" Solution and the "Overall" Solutions? 3.8
   3.3 Description of General Feedback Framework 3.9
   3.4 Alternative Methods for Implementing Feedback 3.12
   3.5 Desirable Features and Attributes Associated with Implementing Feedback 3.17
      3.5.1 The Process should be easily executed and understood in a production environment 3.18
      3.5.2 Need for an Automated Iterative Process 3.19
      3.5.3 Variable Number Of Iterations with Convergence Criteria Determining Termination 3.19
      3.5.4 Convergence Criteria 3.22
      3.5.5 Use of Real Arithmetic or "Bucket Rounding" to Control Accumulation of Matrix Calculations 3.24

4. THE EFFECTS OF FEEDBACK 4.1
   4.1 Selection of Regional Models for Testing Feedback 4.1
   4.2 Operational Characteristics of Feedback 4.3
      4.2.1 Convergence Characteristics 4.3
      4.2.2 Execution Time 4.10
   4.3 Effects on System-wide Travel Characteristics 4.10
   4.4 Introduction of Mode Choice into the Feedback Process 4.20
   4.5 The Effect of Feedback on Model Sensitivity 4.26

SECTION **PAGE**

5. GUIDANCE FOR IMPLEMENTATION OF FEEDBACK 5.1
   - 5.1 Revalidation 5.1
   - 5.2 Resource Requirements (Time and Storage) 5.4
   - 5.3 Round Off Error and Integer Arithmetic 5.8
   - 5.4 Number of Zones and the Impact of Intra-Zonal Trips 5.10
   - 5.5 Starting Conditions and Feedback Variables 5.10
   - 5.6 Assignment Algorithms 5.11
   - 5.7 Composite Impedance Functions 5.12
   - 5.8 Hyper-Sensitivity 5.14
   - 5.9 Averaging 5.15

References .... References 1

Appendix A A.1

LIST OF TABLES

TABLE **PAGE**

- 2.1 Factors Determining the Need for Feedback 2.1
- 2.2 Environmental Indicators Determining Feedback Requirements 2.3
- 2.3 Comparison of Congestion Indicators and Change due to Feedback 2.5
- 2.4 Guidance on Appropriate Use of Feedback Mechanisms 2.8
- 2.5 Feedback Decision Hierarchy 2.12
- 4.1 Effects of Feedback on Model Systemwide Execution Time 4.8
- 4.2 Effects of Feedback on Model Systemwide Average Network Speed 4.18
- 4.3 Effects of Feedback on Model Systemwide Vehicle Miles Traveled 4.19
- 4.4 Comparison of Mode Choice Feedback Options for Salt Lake City 4.22
- 4.5 Comparison of Mode Choice Feedback Options for Memphis 4.22
- 4.6 District to District Impacts of Feedback and Mode Choice: Salt Lake City Model 4.25
- 4.7 Effects of Feedback on Model Sensitivity 4.28
- 5.1 Steps to Adjust Existing Trip Distribution Factors with the Introduction of Feedback 5.3
- 5.2 Storage Requirements for the Results of One Iteration 5.4
- 5.3 Effects of Feedback on Base Models Systemwide Execution Time 5.7
- 5.4 Round-off Error in Total Trips After Feedback 5.9

LIST OF FIGURES

FIGURE **PAGE**

1.1 Feedback Locations within the Four-Step Process 1.2
2.1 Change in System Statistics due to Feedback as a Function of Congestion 2.6
2.2 Change in System Statistics due to Feedback as a Function of Congestion 2.7
3.1 Interrelationships of Travel Demand 3.2
3.2 Feedback Locations Within the Four Step Process 3.3
3.3 Generic Feedback Framework 3.11
3.4 Comparison of Direct Feedback and Method of Successive Averages: Root Mean Square for Trip Interchanges 3.14
3.5 Iterative Process for Data Storage Within the Generic Feedback Framework 3.20
3.6 Impact of Congestion on Number of Iterations Required for Convergence 3.21
4.1 Comparison of Convergence Characteristics for Alternative Feedback Methods: Percent of Links with <10% Change in Volume 4.4
4.2 Comparison of Convergence Characteristics for Alternative Feedback Methods: Percent Change in Average Speed 4.5
4.3 Comparison of Convergence Characteristics for Alternative Feedback Methods: RMS of Volume 4.6
4.4 Comparison of Convergence in Frequency of Person Trips by Percent Change in Person Trips for Salt Lake City Model 4.9
4.5 Comparison of Execution Times for Alternative Feedback Methods: Average Execution Time of Steps Within One Feedback Iteration 4.11
4.6 Comparison of Execution Times for Alternative Feedback Methods: RMS of Volume Versus Execution Time 4.12
4.7 Comparison of Execution Times for Alternative Feedback Methods: Percent Change in Average Speed Versus Execution Time 4.13
4.8 Comparison of Execution Times for Alternative Feedback Methods: Maximum Absolute Change in Person Trip Impedance Between O-D Pairs Versus Execution Time 4.14
4.9 Location of New Facility Tested in Memphis Model 4.15
4.10 Location of New Facility Tested in Salt Lake City Model 4.16
4.11 Salt Lake City Model Superdistrict System 4.24

ACKNOWLEDGMENTS

This report on the incorporation of feedback into travel forecasting was prepared for the Federal Highway Administration (FHWA) under Contract No. DTFH61-93-C-00216 by COMSIS Corporation. Members of the COMSIS research team included William R. Loudon, Larry R. Sieders, James A. Bunch and Janaki M. Parameswaran.

We would like to express our special thanks to David Boyce at the University of Illinois, Chicago for sharing his experience and technical insights throughout the course of this research. In addition, we would like to thank Abdul Razak from the Memphis Metropolitan Planning Commission and Mick Crandall from the Wasatch Front Regional Council for providing us with the data necessary for the research. The following individuals also provided critical review or assistance during the project and we gratefully acknowledge their contributions: Paul Metaxatos and William Thomas, COMSIS Corporation; Keith Lawton, Resource Decision Consultants; Robert Dial, Volpe National Transportation Systems Center; Gary Davies, Garmen Associates; William Allen, Independent Consultant; and Gordon Schultz, Parsons Brinkerhoff Quade & Douglas.

Finally, we would like to thank Brian Gardner and Fred Ducca of FHWA for providing us technical guidance throughout the research effort and in the preparation of this report.

Incorporating Feedback in Travel Forecasting: Methods, Pitfalls and Common Concerns

Project Objectives

The most common method for producing regional or metropolitan area travel forecasts in the United States is to apply the following four modeling steps sequentially:

- *trip generation,*
- *trip distribution,*
- *mode choice, and*
- *route assignment.*

This traditional four-step process passes output from one step to the next as input, as illustrated in Figure 1. While the process has produced forecast results sufficiently accurate for many types of long range transportation planning, it is commonly found that some of the outputs of the process are not consistent with inputs to earlier steps. The research undertaken in this project focused on methods to ensure that link speeds used in each step of the travel forecasting process are consistent with the final speeds estimated in the final step of the process. As a product of this research, a final report was prepared to provide guidance in the application of feedback.

A variety of methods for introducing "feedback" into the process (reintroducing output of one step as input to a previous step) were explored and guidance was developed on when and how to incorporate feedback into the four-step modeling process. Figure 1 illustrates four possible ways in which feedback can be provided in the four-step process and one additional way that feedback can be provided to other modeling steps.

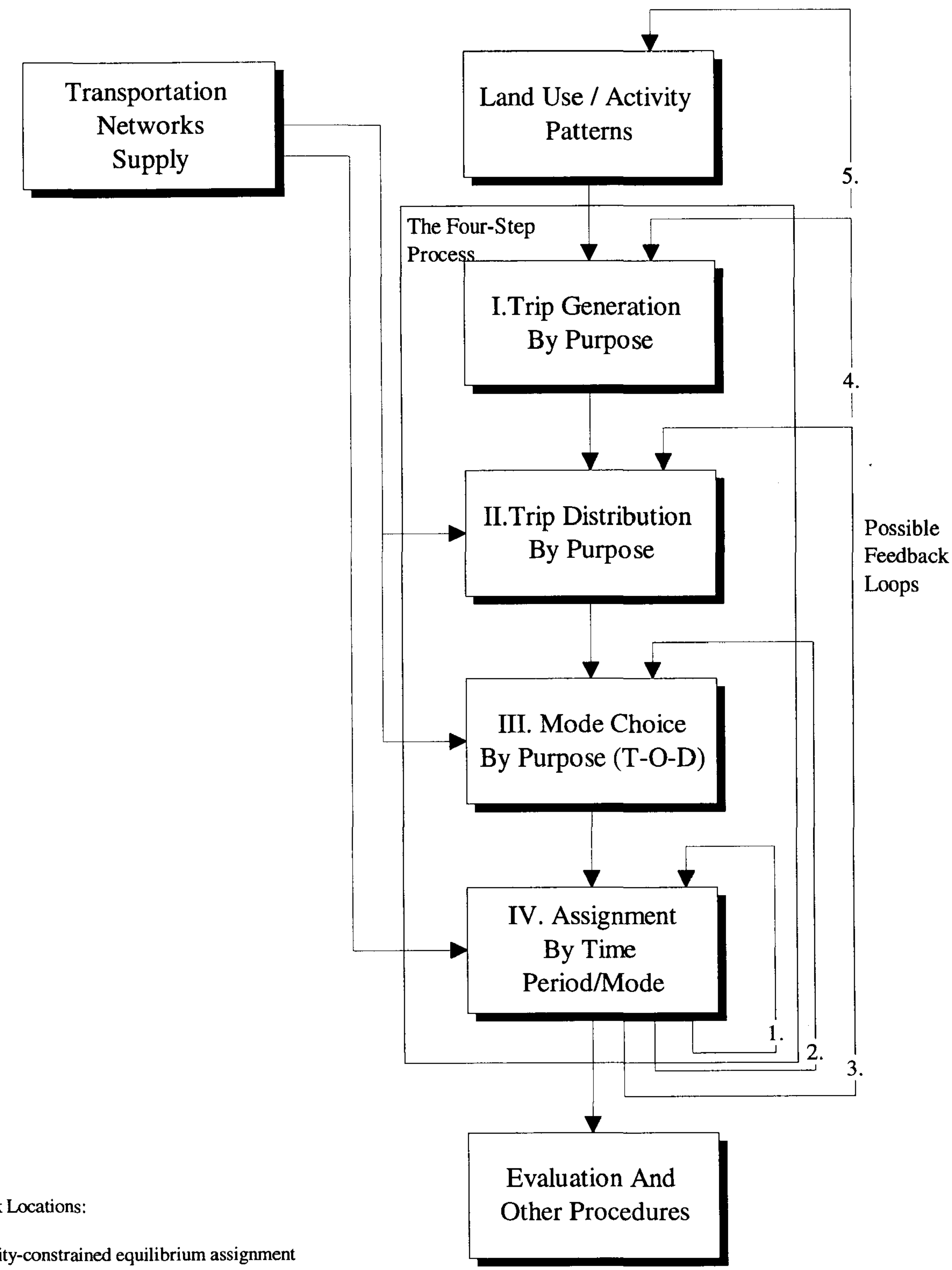
The exploration of methods for introducing feedback into the traditional four-step travel forecasting process is not new. Methods implementing feedback have been used for planning studies in major U.S. metropolitan area for at least twenty years. (Boyce et al, 1970; Boyce, et al 1994; Lawton and Walker, 1993; BMC, 1992; DRCOG, 1992; MWCOG, 1994; PBQD, 1992; Mann, 1993). But introducing feedback using currently available travel forecasting software is complex, is generally cumbersome, requires lengthy execution times, and is prone to significant pitfalls and errors. As a result, few modelers have chosen to pursue implementation of feedback in regional or metropolitan area models despite some of the theoretical and obvious intuitive justifications for doing so. This research effort was initiated because a recent increase in the use of regional and metropolitan area models for forecasting pollutant emissions has resulted in regulatory requirements that may force modelers for major metropolitan areas to incorporate feedback in a way that will produce consistent use of travel speeds throughout the modeling process. Another related motivation is the desire to better capture the effects of congestion on traveler choice behavior and the benefits of congestion management strategies in reducing delay.

The Federal Highway Administration (FHWA) sponsored this research effort to support states and metropolitan planning organizations in their responses to the new regulatory requirements for emissions modeling. To meet this basic objective, the research was designed to address the following questions:

- *Does feedback make a difference in the results of a four-step modeling process and if so, under what conditions?*
- *What methods are available for feedback and what are the advantages and disadvantages of each?*
- *What criteria should be used to determine when feedback has successfully resulted in consistency of speeds in the modeling process?*
- *What guidance can be provided to modelers who choose to undertake the introduction of feedback?*

Central to this research effort was the application of a variety of feedback methods within two case study model systems: the regional travel forecast systems for Memphis, Tennessee and Salt Lake City, Utah. These model systems were chosen because they were readily available to the research team and because they could be used to reflect a range of levels of congestion by manipulating the baseline conditions representing the input to the model system (the transportation network and the land use forecast). The performance of the alternative methods for implementing feedback and the variety of methods for assessing closure could be tested in response to the full range of travel

Figure 1: Feedback Locations within the Four-Step Process



Feedback Locations:

1. Capacity-constrained equilibrium assignment
2. Congested times as inputs to mode split
3. Congested times or composite impedances as inputs to trip distribution
4. Accessibility factors in trip generation
5. Land use - transportation interaction

conditions. From these tests, the research team was able to determine when feedback was likely to make a significant difference in forecast results, which methods are most likely to produce improved accuracy under different conditions, and the overall resource requirements of each method.

Addressing Regulatory Requirements for Feedback

The Clean Air Act Amendments (CAAA) of 1990 significantly increased the role of regional or metropolitan area travel forecasting models in the forecasting of pollutant emission levels for future years in non-attainment areas. The CAAA required the development of a "...comprehensive, accurate, and current..." emissions inventory for oxides of nitrogen (NOx), volatile organic compounds (VOC), carbon monoxide (CO), and small particulate matter (PM_{10}) for every non-attainment area (marginal and worse) as part of a state implementation plan (SIP) for air quality attainment (U.S. Congress, 1990 C.A.A.A.).

The U.S. Environmental Protection Agency's guidance on preparation of an emissions inventory (U.S. EPA, 1992) describes feedback as a necessary part of the travel forecasting process. It cites as support for this point a ruling by the Federal District Court of Northern California, in a suit brought by the Sierra Club against the Metropolitan Transportation Commission of the San Francisco Bay Area. The ruling stated, "where the model had the capability to incorporate feedback effects, the planning agency was obliged to project travel with those effects included." (U.S. District Court for Northern California, 1990). While the EPA did not state the conditions under which the network modeling approach should be used for emissions inventories, the discussion of the importance of feedback applies wherever the network models are to be used.

In a second area of guidance related to the Clean Air Act Amendments of 1990, each state must demonstrate that its transportation improvement programs (TIP), regional transportation plans (RTP), and projects of regional significance conform with the approved state implementation plan (SIP) for air quality attainment (U.S. EPA, 1993). In its final rule for determining conformity, the EPA calls explicitly for feedback in the transportation forecasting process for serious, severe, and extreme ozone non-attainment areas, and for serious carbon monoxide non-attainment areas. The guidance states that the models used in the preparation of transportation plans and programs must have the following elements:

- *The models must show a logical correspondence between an assumed land-use scenario and the future transportation system,*
- *Peak and off-peak travel demand and travel time must be provided,*
- *Methods to estimate traffic speeds and delays must be used that are sensitive to traffic volume in the network model,*
- *A capacity-sensitive assignment methodology must be used for peak-hour or peak-period traffic assignments (feedback within assignment),*
- *Zone-to-zone travel times used to distribute trips between origin-and-destination pairs must be in reasonable agreement with the travel times that result from the process of assignment of trips to network links (feedback between assignment and trip distribution), and*
- *Where use of transit is significant, the final zone-to-zone travel time should also be used for mode split (feedback between assignment and mode split).*

It is further recommended by the EPA that models used in the preparation of plans and programs include the following:

- *A dependence of trip generation on the accessibility of destinations (feedback between assignment and trip generation), and*
- *A dependence of regional economic and population growth on the accessibility of destinations (feedback between the transportation model and the land use model).*

With its guidance on conformity, the EPA significantly strengthened the regulatory requirements for use of feedback in the modeling processes of non-attainment areas.

The recent EPA guidance supporting the Clean Air Act Amendments of 1990 has provided the necessary motivation for modelers in most non-attainment areas to pursue the options for feedback despite the additional time and resource requirements and the potential pitfalls of inappropriate application of the procedures. Further motivation is also provided by a growing interest in management strategies that can achieve greater use of already existing transportation infrastructure for which greater sensitivity to speed differences is necessary if regional models are to be useful planning tools. The U.S. Department of Transportation's initiative for Intelligent Transportation Systems (ITS) funded under the Intermodal Surface Transportation Efficiency Act (ISTEA) has heightened the nation's interest in these management-oriented strategies and has increased the interest in more accurate model systems (Euler and Robertson, 1995). The introduction of feedback mechanisms would appear to be a major step forward in providing additional sensitivity and accuracy in the evaluation of management strategies.

Implementation of Feedback

The primary goal of the implementation of feedback in a traditional four-step modeling process is to provide a process for reaching an overall "equilibrium" within the forecasting system. Equilibrium can be defined as the state of balance in which all interactions have been accounted for and the inputs and outputs of each step of the process are reasonably consistent with one another. The most straightforward application of feedback would take the output from the assignment step in the modeling process and reintroduce it as input to a previous step. This is illustrated by direct feedback between trip assignment and trip distribution, the most common type of feedback currently pursued by modelers and the feedback mechanism of most concern to the EPA. Successful implementation of this basic feedback loop will result in a trip distribution model that determines the underlying pattern of trips within a region using zone-to-zone travel times that are consistent with the final loaded speeds of assignment: the last step in the process. The most common current modeling practice is to use a fixed set of travel times in trip distribution that may or may not reflect capacity-constrained conditions. This often results in significant differences between the speeds used for trip distribution and those that result from the assignment.

Feedback always involves the transfer of data from assignment to a previous point in the modeling process. This even includes an internal feedback within the assignment step that is necessary for equilibrium assignments. Feedback can include the reintroduction of assignment data at any point in the process, including the land use activity forecasting process that precedes the traditional four-step transportation model steps or the trip generation step. Regardless of the number of steps included within the feedback loop, the underlying concept remains the same: iterative transfer of data from the end of the process back to earlier steps until the difference between the values for input data and output data are within an acceptable range.

Convergence Criteria

In a well-designed feedback process, the values for input variables and output variables should converge toward common values. The development of that feedback mechanism requires the selection of appropriate convergence criteria to inform the modelers when the iterative application of the feedback loop can be ended and the final assignment results used.

The two most important variables for determining if equilibrium is achieved in the feedback process, especially for air quality analysis, are volumes on links and average operating speeds on links. Because of the way in which speeds are estimated in traditional travel forecasting models, volume and speed are directly related through a functional relationship, so convergence with respect to volume usually implies convergence with respect to speed and vice versa.

The selection of an appropriate convergence criterion is complicated, however, and a wide variety of measures can be constructed to reflect either travel volumes or travel speeds. For either, measures can be constructed to reflect the region as a whole, sub-groupings of links within the regional network (functional classifications, area-type classifications, sub-regional areas, screenlines, cordons or corridors) or specific links. In general, more fluctuation in values is experienced between iterations at the link level than for the more aggregate measures. But the choice of which measure is most appropriate for use as a convergence criterion depends upon the specific application. If the focus of the application is on a particular facility, the convergence criterion might be something like the following:

A change of five percent or less between iterations in the vehicle miles of travel assigned to the links on the facility.

If an analysis is regionally oriented, as might be the case in modeling for the regional transportation plan for a conformity analysis, an appropriate convergence criterion might be the following:

At least ninety-five percent of the links in the system with a percent change in volume less than or equal to five percent.

It is possible to see an apparent convergence with respect to one measure without achieving a true equilibrium or true convergence. If the feedback is implemented to include multiple steps in the four-step process, compensating change in the distribution of trips on the system can result in a low percentage changes in a particular measure while actually representing fairly significant changes in travel behavior. As an example, a feedback mechanism that can change the trip distribution may result in more trips in a corridor but with shorter length than in a previous iteration. If the convergence criterion is vehicle miles traveled on a facility, the assumption of equilibrium being achieved may be an error. For this reason, more than one convergence criterion might be needed to guarantee a higher probability of a true convergence when the criteria are met. Some of the other measures that might be used in addition to the volume and speed measures mentioned earlier include the following:

- *Maximum percent change in trips between an origin and destination,*
- *Percent change in origin-to-destination travel time,*
- *Percent change in mean trip length, or*
- *Percent change in vehicle delay.*

In addition to the specific concrete travel characteristics suggested above as measures of convergence, there are also at least two system-wide functions of travel times and delays common in travel assignment packages that might be used:

- *Percent change in the objective function of the equilibrium assignment (Sheffi, 1985; Florian, 1991; Boyce et al, 1994; Evans, 1976), or*
- *Percent change in the Gap or Normalized Gap functions (Boyce, 1995; Florian, 1991; Van Vuren, 1995).*

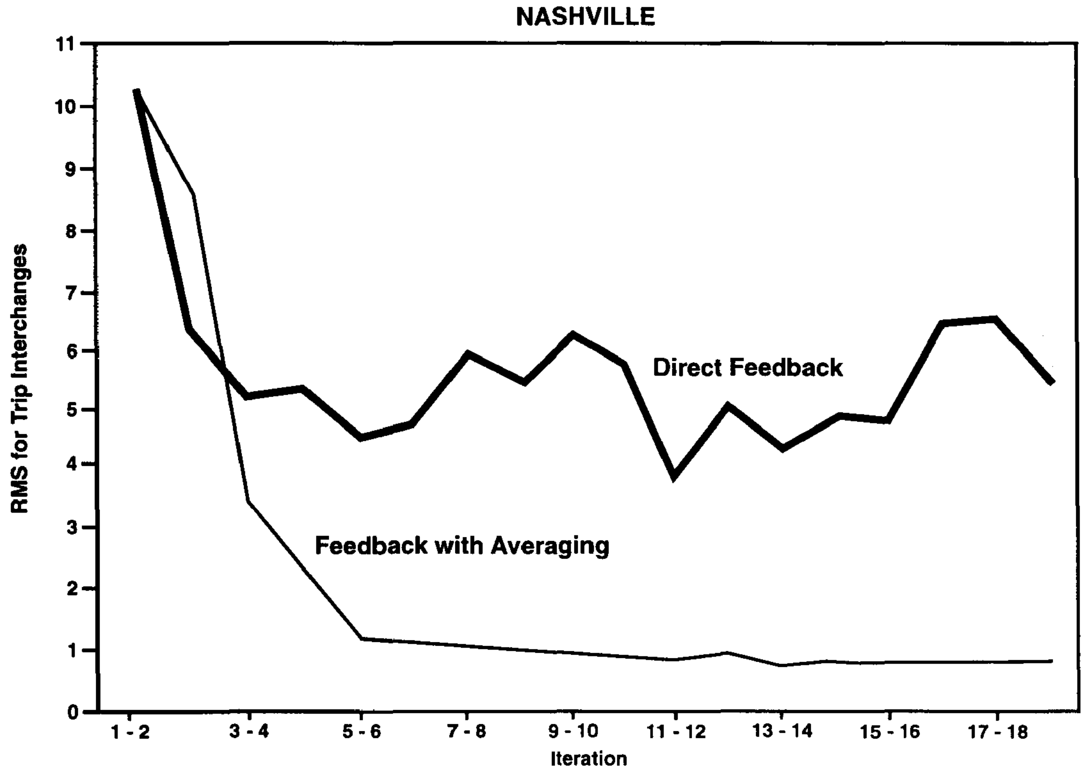
Both are used internally in traffic assignment to determine when a user equilibrium in the system has been achieved. As such, both represent system-wide measures that use link-specific assignment information as measures of changes in travel patterns or conditions. The measures have also been extended to incorporate the results of the other steps in the travel forecasting process.

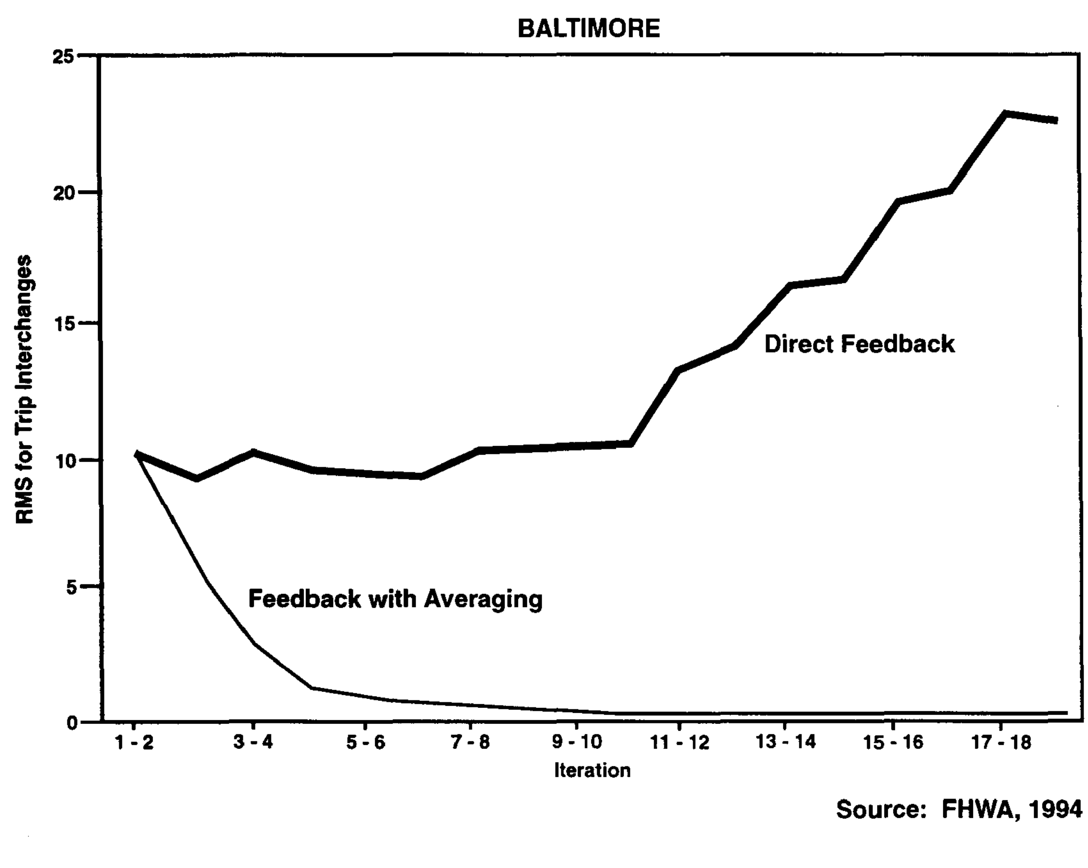
Methods for Introducing Feedback

Numerous researchers and planning practitioners have experienced difficulty achieving convergence in a feedback process when a "Direct Method" of feedback is used: the output of assignment is used directly, unaltered, as input for a previous step in the modeling process. One example illustrated in Figure 2 is provided by a research effort undertaken internally by the Federal Highway Administration. Using data from Baltimore, Maryland and Nashville, Tennessee, the researchers found that there was instability in the approach from iteration to iteration and no sign of convergence to a consistent set of values. In most cases, convergence will occur using the Direct Methods but often only after many iterations and the consumption of considerable clock time and computer time. Florian et al. (1975) demonstrate mathematically and by example that the Direct Method will not always converge to the correct solution and may not converge at all.

A number of alternatives to the Direct Method have been identified by previous researchers and practitioners as ways to reduce processing time and assure convergence. All of the methods represent alternatives for using information from all previous iterations to move the next iteration toward a convergent solution. The methods use somewhat different approaches either in the assignment algorithm or in the method for combining results of previous iterations to produce new input values. The four alternative methods chosen for application in this research are as follows:

Figure 2: Comparison of Direct Feedback and Method of Successive Averages Root Mean Square for Trip Interchanges





Source: FHWA, 1994

- *Method of Successive Averages with Equilibrium Assignment (MSA-EQA) - provides equal weight to each previous iteration's equilibrium assignment results.*
- *Method of Successive Averages with All-or-Nothing Assignment (MSA-AON) - same as MSA-EQA but each assignment is made on single best-path basis.*
- *Method of Optimal Weighting with Equilibrium Assignment (MOW-EQA) - computes an optimal weighting for each iteration's equilibrium assignment.*
- *Method of Optimal Weighting with All-or-Nothing Assignment (MOW-AON) - same as MOW-EQA but each assignment is made on a single best-path basis.*

For all four of these alternative methods, the volumes from previous iterations are averaged with the volumes from the most recent assignment and new input speeds are determined based upon the averaged volumes. The speeds from previous iterations are not averaged directly because of the non-linear relationship between volume, capacity, and speed. All of these methods address the way in which output from assignment is manipulated prior to reintroduction as input to a previous step. The application of any one of the alternative approaches is basically the same regardless of where in the four-step process the assignment data are being fed back.

The Effects of Feedback

To test the applicability of feedback in the traditional four-step process and to provide an assessment of alternative methods for implementing feedback, a case-study approach was used. Model systems for two major metropolitan areas; Memphis, Tennessee and Salt Lake City; Utah; were selected for the case-study applications. The two sites provided a variety of land-use, network, and level-of-service characteristics and also represented two metropolitan areas for which the research team already had a significant amount of model data available.

The model system for the Memphis metropolitan area is maintained by the Memphis Metropolitan Planning Organization and has been validated for a 1988 base year. A regional population of slightly less than one million is represented in 365 zones. The highway network for the model has all major roads coded and the transit system has three types of modes: regular/local bus, blazers or express bus, and north/south or cross-town routes. The trip purposes of the model are home-based-work, home-based-other, non-home-based, trucks and taxis, and external trips. A gravity model is used for trip distribution and a multinomial logit model is used in the mode choice procedure.

The model for the Salt Lake City metropolitan area uses 556 zones to represent the regional land use which also supports a population of about one million. A base year of 1990 has been established and a validation has been performed for that year. The highway network also has most of the major roadways coded and includes local and premium bus services in the transit network. Trip purposes modeled include home-based-work, home-based-other, non-home-based, home-based college, commercial, and external trips. A gravity model is the basis for trip distribution, and a nested-logit model has been developed for the mode-choice process to model five modes: drive alone, two-person carpool, three-plus-person carpool, local bus, and premium bus.

The two case-study sites provided reasonable variation because the baseline conditions: Salt Lake City included considerable congestion while the Memphis base-year model had only a small amount of congestion in selected locations. The discernible difference between the two case-sites provided sufficient opportunity to use sensitivity testing with the two models to produce a wide variety of conditions. Sensitivity tests were conducted by testing the effects of twenty-five percent uniform growth throughout the area, twenty-five percent in radial growth along selected growth corridors and the effects of a major new facility being added into the highway network.

Effects on System-wide Travel Characteristics

Table 1 presents the baseline results from application of the Direct Method and the two MSA options for an "assignment-to-trip-distribution" feedback loop in the two test-case cities[1]. Using system-wide average speed as a measure of effect, the results of

[1]Because of the specific characteristics of the test case models, the Method of Optimal Weighing could not be tested for its effect on system-wide travel characteristics; however, a later section of this report compares its convergence characteristics with those of the Direct Method and the Method of Successive Averages.

the two case studies indicate that feedback can produce significantly different results when congested conditions occur, but has very little effect where there is little or no congestion. In the Salt Lake City model, in which the average baseline speed without feedback was roughly 22 miles per hour, all three of the feedback methods produced system-wide speed increases between 21 and 23 percent for the baseline year. But for the Memphis metropolitan area, where the system-wide model average baseline speed without feedback was roughly 42 miles per hour, feedback produced a system-wide increase of less than two percent. Even when 25 percent uniform growth was added in the Memphis model, the increase in system-wide average speed over the no-feedback baseline was less than 3 percent. In the more congested Salt Lake City model system, 25 percent growth produced a difference of roughly 50 percent in system-wide speed between the no-feedback baseline and the three alternative feedback mechanisms. When the growth was concentrated radially, there was an even greater difference between the no-feedback baseline and the three alternative feedback methods.

Table 2 reflects a somewhat similar pattern of change in results from feedback where the system-wide vehicle miles traveled is the measure. Because the feedback loop tested in Memphis and Salt Lake City allowed for the use of an equilibrium set of travel times in the trip distribution step, a different trip-length distribution could result for a fixed number of total vehicle trips. In both cases, feedback resulted in a reduction of system-wide vehicle miles traveled reflecting shorter mean travel lengths. Again, the change produced by feedback is significantly greater in the more congested Salt Lake City model (a reduction ranging from 11.5 percent to 12.5 percent) than in the Memphis model (where the change ranged from 2.2 percent to 2.5 percent).

The sensitivity testing with the two test case models demonstrated a consistency in the nature and direction of change produced by the introduction of feedback. Although not all of the impacts of feedback on system characteristics are reported here, the tests indicated that feedback produced the following changes in assignment results:

- *Average link speeds are increased,*
- *Average travel time is decreased,*
- *Average travel distance is decreased,*
- *Average Volume/Capacity ratio is decreased, and*
- *Total vehicle miles travel is decreased.*

While the direction of change was consistent in the observed results, the magnitude of the change for each of the above measures varied significantly and was almost always directly related to the amount of congestion in the network being modeled: the greater the level of congestion, the greater the change introduced by feedback. The systematic changes in results produced by the introduction of feedback have two significant implications. The first is the need for recalibration of a baseline model after feedback has been introduced into the modeling system. The second is the need for the use of feedback modeling to accurately reflect the level of impact of increasing congestion on trip distribution and travel speeds.

Convergence Characteristics of Alternative Feedback Methods

The test case results also clearly demonstrate the value of using one of the averaging methods over the direct feedback method. The averaging methods each produced faster and more complete convergence. Figure 3 provides a comparison of the Direct Method results with the MSA-EQA results for Salt Lake City. Both methods produced roughly the same change in speeds from about 18 miles per hour to about 22 miles per hour, but the MSA-EQA shows virtually complete convergence after the sixth or seventh iteration while the Direct Method is still oscillating at a level of one percent to two percent in the ninth and tenth iterations. Both methods that used successive averages produced almost identical convergence results. The MSA-AON required only fifteen all-or-nothing assignments, however, while the MSA-EQA required seventy all-or-nothing assignments.

Table 3 provides a comparison of the execution times for the three feedback methods and for the no-feedback baseline. For the test cases, feedback resulted in execution times roughly five to eight times that of no feedback for the Memphis model and 1.5 to 1.9 times that of no feedback for the Salt Lake City model. Of the three feedback methods tested, the one method using all-or-nothing assignments had a noticeably shorter execution time but also took considerably more iterations to converge. It should be noted that the different applications did not terminate in relation to a specific convergence criterion but were instead set to run for a fixed number of iterations.

Table 1: Effects of Feedback on Model Systemwide Average Network Speed

Feedback		Test Scenario			
Method	Number of Iterations	Base	25% Uniform Growth	25% Radial Growth	New Facility
Memphis		Percent Change From "No Feedback" Speed	Percent Change From "No Feedback" Speed	Percent Change From "No Feedback" Speed	Percent Change From "No Feedback" Speed
No Feedback	1	41.6 mph	39.4 mph	39.1 mph	43.3 mph
Direct	10	1.1%	2.4%	2.9%	0.6%
MSA (Equilibrium)	10	1.1%	2.4%	2.1%	0.6%
MSA (A-O-N)	15	1.3%	2.5%	2.1%	0.8%
Salt Lake					
No Feedback	1	22.0 mph	14.4 mph	12.9 mph	23.7 mph
Direct	10	22.8%	47.8%	62.6%	13.1%
MSA (Equilibrium)	10	21.3%	48.2%	66.6%	12.6%
MSA (A-O-N)	15	23.0%	50.2%	68.1%	14.4%

Note: For No Feedback Case the Average Network Speed is shown. For the Direct and Method of Successive Averages cases the % Change from No Feedback is shown.

Table 2: Effects of Feedback on Model Systemwide Vehicle Miles Traveled

Feedback		Test Scenario			
Method	Number of Iterations	Base	25% Uniform Growth	25% Radial Growth	New Facility
Memphis		Percent Change from "No Feedback" VMT	Percent Change from "No Feedback" VMT	Percent Change from "No Feedback" VMT	Percent Change from "No Feedback" VMT
No Feedback (VMT)	1	15,824,577	19,559,521	19,849,273	16,273,549
Direct	10	-3.5%	-5.0%	-5.5%	-3.2%
MSA (Equilibrium)	10	-3.2%	-4.7%	-5.1%	-2.9%
MSA (A-O-N)	15	-3.6%	-5.0%	-5.4%	-3.1%
Salt Lake					
No Feedback (VMT)	1	17,796,907	22,668,632	22,794,044	18,004,694
Direct	10	-12.5%	-12.0%	-12.1%	-6.7%
MSA (Equilibrium)	10	-11.6%	-11.1%	-11.5%	-6.1%
MSA (A-O-N)	15	-11.5%	-10.8%	-11.2%	-6.0%

Note: For No Feedback Case the Vehicle Miles Traveled is shown. For the Direct and Method of Successive Averaging cases the % Change from No Feedback is shown.

Figure 3: Comparison of Convergence Characteristics for Alternative Feedback Methods in the Salt Lake City Model

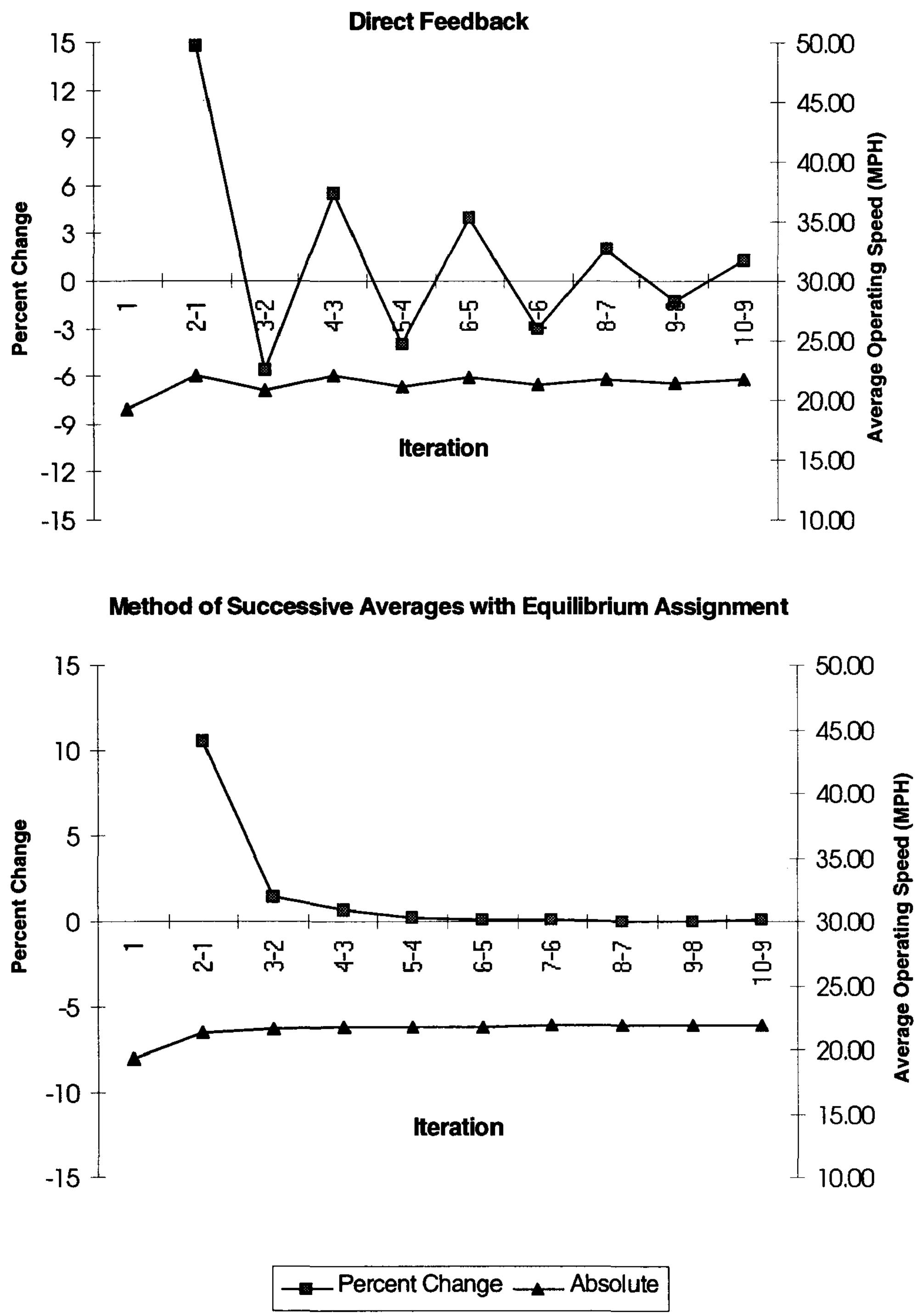


Table 3: Effects of Feedback on Model Systemwide Execution Time

Feedback		Execution Time (in minutes)						
Mechanism	Number of Loops or Iterations	Distribution	Transit	Mode Choice	Assignment	Updates	Evaluation	Total
Memphis								
No Feedback	1	1.27	2.17	0.65	2.28	0.00	0.00	6.37
Direct	10	13.83	3.35	0.68	22.83	4.67	18.83	63.20
MSA (Equil)	10	12.33	3.35	0.68	22.83	13.67	18.67	71.03
MSA (A-O-N)	15	17.00	3.35	0.68	7.25	18.25	26.00	72.53
Salt Lake								
No Feedback	1	2.27	58.03	42.40	5.48	0.00	0.00	108.18
Direct	10	23.00	58.03	42.40	55.00	16.50	40.67	235.60
MSA (Equil)	10	21.00	58.03	42.40	50.67	34.00	37.67	243.77
MSA (A-O-N)	15	33.50	58.03	42.40	11.00	52.75	61.25	258.93

Methods Using Optimal Weighting

Extensive research has been conducted on methods for feedback that use an optimal weighting for each iteration rather than a fixed weighting as used in the MSA-EQA and MSA-AON previously discussed (Evans, 1976; Horowitz, 1991; Florian et al., 1975; Boyce et al., 1994; Boyce et al., 1988; Walker and Peng, 1995; Sheffi, 1985; Ortuzar and Willumsen, 1990). Evans first proposed one of the most widely used methods for optimal weighting. Evans' algorithm finds the weight for averaging the most recent assignment and trip distribution results of an iteration with the results from previous iterations that will minimize an objective function that includes a representation of the volume-delay function and the zone-to-zone friction factors used in trip distribution. Because of the characteristics of the objective function in Evans' algorithm, the method produces the best convergence results when the trip distribution model uses an exponential friction function that matches that in Evans' algorithm. Neither of the two test-case model systems had such a trip distribution model and so one model (Salt Lake City) was adapted for application of Evans' algorithm. The adaptation produced a different distribution of trips between zones in the baseline (no feedback) application and so the results cannot be compared to the previous results of the sensitivity tests for the two test-case models. This section provides a comparison of the convergence characteristics of Evans's algorithm with that of the other feedback methods.

When tested in feedback in the Salt Lake City model, the Method of Optimal Weighting (MOW), as represented by Evans' algorithm, demonstrated convergence characteristics almost identical to the Method of Successive Averages. As indicated by Figure 4, MOW-EQA demonstrated convergence characteristics similar to MSA-EQA and the performance of MOW-AON was similar to that of MSA-AON. Similar results were obtained using a comparison of the percent change in volume and speed. The applications in the Salt Lake City model system showed no significant improvement in convergence characteristics with MOW and the execution time was considerably greater than MSA as illustrated by Figure 5. While the results for Salt Lake City do not indicate that the additional complexity of the MOW produces better or faster convergence, other researchers have suggested that for large networks with extreme congestion, MOW-AON may produce more efficient convergence than either of the MSA options (Walker and Peng, 1995).

Inclusion of Mode Choice in the Feedback Process

In areas where significant transit service exists or is planned, the 1990 CAAA Conformity Guidance suggests the use of the

Figure 4: Comparison of Convergence Characteristics of Feedback Processes for the Salt Lake City Model
Root Mean Square Change of Volume

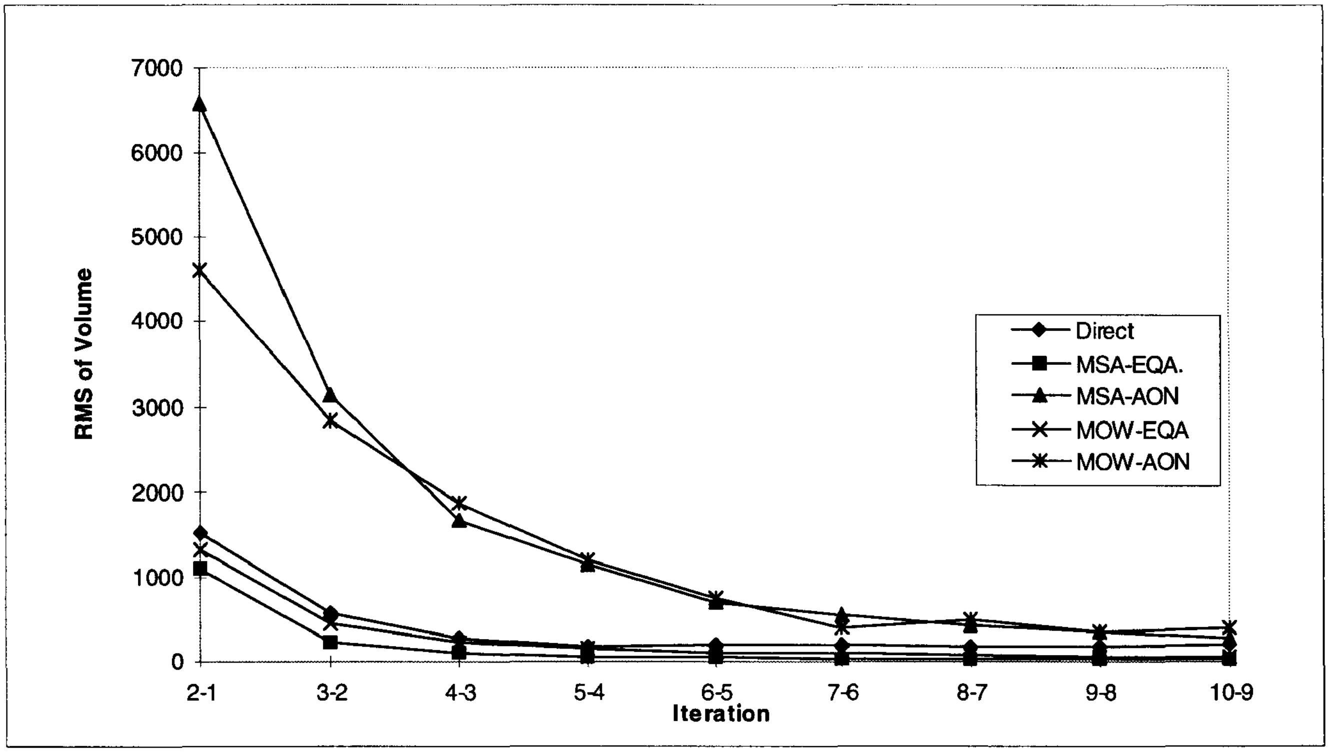
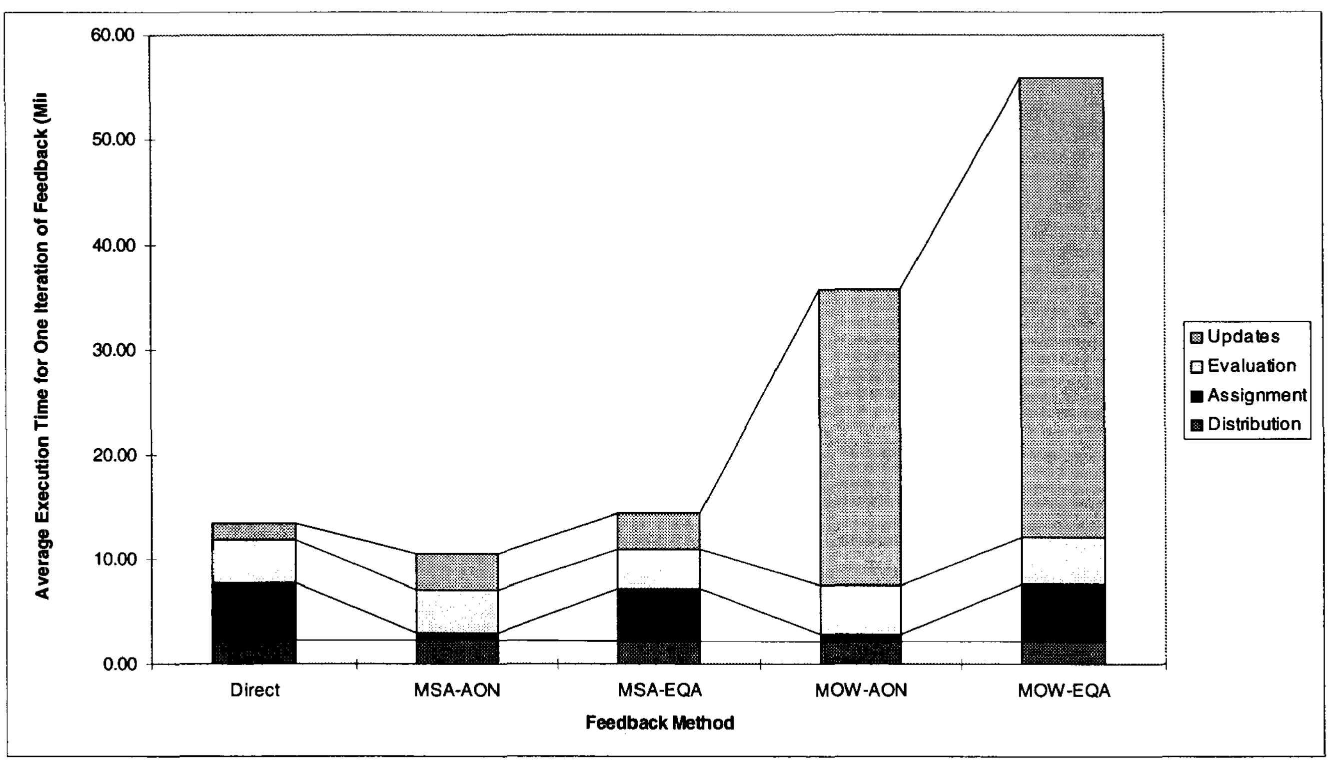


Figure 5: Comparison of Execution Times for Feedback Methods for Salt Lake City Model
Average Execution Time for an Iteration (Minutes)



final "equilibrated" highway times (trip distribution input times in agreement with output times from assignment) in estimating mode shares.

> Where use of transit currently is anticipated to be a significant factor in satisfying transportation demand, these times (the final highway times) should also be used for modeling mode choice (U.S. EPA, November 1993).

There are two basic options for including mode choice in a four-step modeling process that includes feedback. The options are as follows:

- *Post Feedback Mode Choice - The simplest option applies the mode choice model after feedback is applied between trip distribution and assignment. Default factors to convert person trips to vehicle trips are used within each iteration of feedback.*

- *Integrated Mode Choice Within Feedback - In this option mode choice is applied within each iteration of feedback. It replaces the use of default person-to-vehicle-trip conversion factors with a full mode choice run for each iteration of the feedback process.*

These options can be implemented using only highway travel times (impedances) for trip distribution or using a composite impedance to reflect the level of service by all modes.

The two options for incorporating mode choice in feedback were implemented in the two test-case model systems to assess the effects of the options on modeling results and on execution time. In both test-case models, the MSA-EQA was used as the basic feedback mechanism and only highway travel times were used in trip distribution. The model systems for Memphis and Salt Lake City could not be adapted for use of a composite impedance measure in trip distribution within the resources of the project.

When mode choice was included in the feedback process, there was little change in the results for either of the two test case models. As indicated in Tables 4 and 5, the number of transit trips changed less than one percent in the Memphis model. In the Salt Lake City model, the number of transit trips decreased by roughly four percent but that represented a shift in total travel of only about one-twentieth of one percent. Despite the small change in the number of transit trips in Salt Lake City, the inclusion of mode choice in the feedback loop did result in an additional increase in average system-wide speed of 21.3 percent when mode choice was run using equilibrated speeds from an assignment-to-distribution feedback (Option 1) and a 37.0 percent increase in speed when mode choice was integrated into each feedback iteration (Option 2).

Although the change in the number of transit trips in the two test case models was small, the change probably has significant implications for the test-case models where the total share of travel by transit was small (0.8 percent in Memphis and 1.5 percent in Salt Lake City). Application of feedback with mode choice incorporated into the process may very well produce more significant changes in a model for a metropolitan area with a more significant share of travel by transit. Such an outcome is suggested by the nature of the difference in results between Memphis and Salt Lake City. The additional transit use and congestion in the Salt Lake City model resulted in more significant changes in results when feedback with mode choice incorporated was introduced.

The specific nature of the change in the Salt Lake City results when feedback with mode choice was introduced is also significant. Most of the change results from a shift in the distribution of trips along congested routes, which are most often the routes where transit services exist. By linking origin zones with destination zones that are closer and whose linkage avoids congested routes, the feedback process reduces the number of trips in corridors where transit is more competitive. This result is illustrated by the reduction in average trip length, the increase in average system-wide speed and the decrease in transit trips.

The results from Salt Lake City, illustrated in Table 4, indicate that integrating mode choice into the feedback process can significantly increase the execution time for the model system. In the case of the Salt Lake City model, execution time increased from 108 minutes (1.8 hours) without feedback to 1085 minutes (18.1 hours) when feedback was introduced with mode choice fully integrated. By contrast, the execution time for feedback with post-feedback application of mode choice was only 243 minutes (4.1 hours). The incorporation of mode choice into the feedback process on each iteration significantly increased execution time, adding fourteen hours in the case of the Salt Lake City model. As indicated in Table 5, the increase in execution time was not as great in the Memphis model but

Table 4: Comparison of Mode Choice Feedback Options for Salt Lake City

	Mode Choice with No Feedback	Post-Feedback Mode Choice	Feedback with Integrated Mode Choice
Person Trips by Mode			
Auto	3,188,247	3,188,727	3,189,991
Transit	43,734	42,254	41,990
Total	3,231,981	3,231,981	3,231,981
Statistics			
Average Speed (mph)	22.02	26.72	30.17
Average Trip Time (minutes)	18.15	16.23	17.20
Average Trip Length (miles)	6.40	5.92	6.07
Execution Time (minutes)	108	244	1,085

[1] The feedback method was MSA with equilibrium assignment.

Table 5: Comparison of Mode Choice Feedback Options for Memphis

	Mode Choice with No Feedback	Post-Feedback Mode Choice	Feedback with Integrated Mode Choice
Person Trips by Mode			
Auto	3,138,128	3,138,301	3,138,328
Transit	24,661	24,488	24,461
Total	3,162,789	3,162,789	3,162,789
Average Statistics			
Average Speed (mph)	41.60	42.07	42.07
Average Trip Time (minutes)	8.92	8.76	8.75
Average Trip Length (miles)	6.13	6.04	6.09
Execution Time (minutes)	6	71	103

[1] The feedback method was MSA with equilibrium assignment.

the mode-choice procedure was a far less complex algorithm than would be used in most modeling efforts where mode choice was of specific interest.

The results from the test cases suggest that incorporation of mode choice in feedback can result in a significant change in results, but only when there is congestion in the network and when transit carries a significant share of regional trips. Because the full integration of mode choice into feedback dramatically increases execution time, incorporation of mode choice after feedback should be considered whenever transit is not a major regional mode.

The Effect of Feedback on Model Sensitivity

Previous sections of this chapter have demonstrated how feedback can affect the results of a model when there is congestion in the network being modeled. The comparisons made in the previous sections were for prescribed baseline conditions, however, and merely suggest the need to recalibrate a model to match observed travel characteristics for those baseline conditions. Once recalibrated, the model with feedback would generally produce travel characteristics for the baseline condition similar if not identical to those of the model without feedback. The true test of the effect of feedback on the output of a modeling system must be based on the difference in results from forecasting with a recalibrated model with feedback and a calibrated model system without feedback.

The resources of this research project did not allow for a full recalibration of either of the test case models with feedback incorporated. As a result, a true test of the model sensitivity and forecasting is not possible. A reexamination of the result of the sensitivity test for the Memphis and Salt Lake City models can provide a useful indication of the effect of feedback on sensitivity of forecasts, however, by comparing the percent change from baseline to the conditions of the sensitivity tests (25 percent uniform growth, 25 percent radially concentrated growth and a new facility). For the model without feedback and for each of the models with feedback, the differences in percentage change provide an indication of how sensitive the model alternatives are to changes that would produce more or less congestion in the network.

Table 6 provides a comparison for three system-wide performance measures: average speed, vehicle miles traveled and average V/C ratio. The results presented in the table suggest that the model with feedback is less sensitive to growth or to strategies designed to reduce congestion. In both model systems, the test of the high-growth scenarios produced less decrease in average speed and less increase in average V/C ratio in the models with feedback than in the models without feedback. This was true for both the uniform growth scenario and the radially-concentrated growth scenario. The test of a major new roadway facility produced a decrease in congestion (as reflected in the reduction in average V/C ratio and the increase in average speed) for all of the models, but the decrease in congestion was less in the models with feedback than in the models without feedback.

A similar conclusion about model sensitivity does not seem appropriate with respect to changes in VMT. The models with feedback did not consistently produce less change in VMT when alternative growth scenarios were tested as was the case for average speed and V/C ratio. Unique location-specific characteristics can, in some cases, result in a greater change in VMT with feedback. As illustrated in Table 6, the addition of a major new roadway facility produced an increase in VMT in all of the models but the increase in VMT in the models with feedback was slightly more than in the models without feedback.

The conclusions on the sensitivity of models with feedback suggest that a recalibrated model with feedback may provide a better representation of speeds and travel times but may show less benefit from projects designed to reduce congestion or improve speeds. Likewise, models with feedback will probably show less deterioration of speed and less overall congestion as a result of growth in trips and VMT.

Guidance in the Application of Feedback

When Feedback Should Be Considered

The application of a variety of feedback methods for the two test case model systems clearly demonstrated that feedback only produces a change in modeling results when there is congestion predicted in a baseline run of the model without feedback. Feedback produced significant changes in the Salt Lake City model where congestion existed in the baseline application but produced only very slight change in the results for Memphis where there was no significant congestion. Some impact of

Table 6: Effects of Feedback on Model Sensitivity

Change in Model Systemwide Average Speed from Baseline

Method	25% Uniform Growth	25% Radial Growth	New Faciltiy
Memphis			
No Feedback	-5.2%	-5.9%	4.1%
Direct	-4.0%	-4.3%	3.5%
MSA (Equilibrium)	-4.0%	-5.0%	3.5%
Salt Lake			
No Feedback	-34.5%	-41.5%	7.6%
Direct	-18.1%	-19.5%	2.9%
MSA (Equilibrium)	-16.8%	-16.5%	3.7%

Change in Model Systemwide V/C Ratio from Baseline

Method	25% Uniform Growth	25% Radial Growth	New Faciltiy
Memphis			
No Feedback	23.7%	25.4%	-8.0%
Direct	21.7%	22.7%	-6.6%
MSA (Equilibrium)	21.8%	22.9%	-6.8%
Salt Lake			
No Feedback	27.2%	27.0%	-2.6%
Direct	20.8%	21.1%	-1.1%
MSA (Equilibrium)	22.1%	22.2%	-1.1%

Change in Model Systemwide Vehicle Miles of Travel from Baseline

Method	25% Uniform Growth	25% Radial Growth	New Faciltiy
Memphis			
No Feedback	23.6%	25.4%	2.8%
Direct	21.7%	22.8%	3.2%
MSA (Equilibrium)	21.8%	23.0%	3.2%
Salt Lake			
No Feedback	27.4%	28.1%	1.2%
Direct	21.4%	21.9%	2.2%
MSA (Equilibrium)	21.1%	21.1%	1.6%

feedback was noted in Memphis, however, after congestion was artificially introduced into the model network through representation of significant growth in the number of trips.

The test applications in Salt Lake City demonstrated that the effects of introducing feedback were not uniform throughout the network but were specifically correlated with the location of the congestion in the network. The feedback process changed the paring of trip origins and destinations in the trip-distribution process and resulted in fewer trips being made between zones connected by congested links and increased the trips between zones connected by uncongested links. The research clearly demonstrated that feedback affects not only the aggregate travel characteristics, such as trip length and average speed, but also the geographic variance in travel characteristics within a region. The research demonstrated that wherever significant congestion might exist in a baseline or future year network, feedback can produce significantly different results. These findings would suggest inclusion of feedback to the trip distribution step wherever congested is expected in the network and inclusion of feedback to mode choice when transit or HOV use is significant. The research was not sufficient to determine whether feedback should also include other steps in the process (trip generation or land use). The model systems used in the test case did not permit sufficient testing of feedback to these other steps.

Appropriate Feedback Methods

The test applications of feedback in sample networks demonstrated that the use of a method that averages previous iterations when calculating new input provides significantly better performance in reaching convergence than a Direct Method that reintroduces only the results of the last iteration. Of the methods tested that included averaging, the Method of Successive Averaging with Equilibrium Assignment (MSA-EQA) demonstrated superior performance characteristics without an appreciable increase in resource requirements over the Direct Method. Others have reported that in extremely large systems with significant congestion there may be advantages to using the more complex processes of mathematical optimization of the weights used to average the results from previous iteration. This occurs when the time required to reach equilibrium in assignment far exceeds the time required for a trip-distribution run.

Recalibrating After Feedback Has Been Introduced

Virtually all four-step modeling processes that are in use today have been calibrated to produce results for a baseline year that reasonably match observed travel characteristics: screenline volumes, volumes on specific roadway facilities, speeds on specific facilities or ridership on existing transit services. The process of calibration usually includes the adjustment of model parameters in one or more of the steps in the four-step process. If the introduction of feedback results in a significant change in any of the travel characteristics, recalibration of the baseline model will be required before the model can be used for forecasting future travel conditions. The most significant need for recalibration will almost certainly be in the trip distribution step where friction factors are used to ensure that the trip distribution model produces a trip-length distribution similar to that reported in a home interview survey, the Census Journey to Work tables or from some other observed data source on trip length. Recalibration may also be required in the mode choice model if model parameters were adjusted to compensate for previously biased estimates of roadway operating speeds.

Common Pitfalls

Most modelers who have attempted to introduce feedback into the traditional four-step modeling process have been the victims of one or more of the common pitfalls of introducing feedback. The process is complex and should be undertaken with thorough checks and reviews to ensure that proper caution has been taken and the system is operating correctly.

Excessive Storage Requirements: One of the most common pitfalls of feedback processes is excessive storage use. As previously indicated, the feedback method that uses information from all previous iterations will generally result in the fastest convergence of the process. Retaining the full information from each iteration throughout the process until closure is achieved will quickly consume the available storage of most microcomputer systems. An efficient method of averaging that uses the information from each iteration as it is completed and then deletes the results of the run, as in the case for MSA, is necessary to avoid the storage problem.

Errors due to rounding: Even a modeling system with a relatively small number of zones (300 to 400) produces an enormously large number of zone-to-zone interchanges in the trip-distribution process for each trip purpose modeled. For efficiency in the modeling process and conservation of both memory and storage, integer representation is frequently used in trip distribution. Rounding errors can be significant if an appropriate method for rounding is not introduced into the process. This is particularly relevant when changes in the trip table are being examined between iterations or between the beginning and the end of a feedback process. Some travel forecasting packages now have capabilities for smaller zone systems to represent tables as fractional (or real) values without sacrificing resource efficiency For large zone systems or where fractional values cannot be retained, a "bucket rounding" method that keeps each fractional element and adds it back in when accumulated to a whole number can preserve the total number of trips in the trip table.

Hypersensitivity: A basic assumption underlying the application of feedback is that travelers base all travel decisions on differences in times and costs between the choice options. It is generally recognized that there are other determinants of travel choice, but these other influences are often not incorporated into the modeling process. This is particularly relevant in the case of feedback because a number of factors besides time or cost are known to affect an individual's choice of where to travel. An individual may choose a job location because of the salary offered or the nature of the work. Similarly the location of a place to live might be based on characteristics of the neighborhood, characteristics of a specific house, and the price of housing in the neighborhood. The linkage of the home and job location for that individual is likely to be only partly determined by the travel time and cost between the two. The introduction of feedback into trip distribution assumes that a change in travel time from the routes connecting the home and the job relative to the routes connecting other zone pairs may induce the traveler to change either home or job location.

A significant change in the level of congestion in a network between a base year and a forecast year can result in a significant shift in trip distribution when feedback is being implemented. This predicted change might be significantly greater than would be expected in reality if the forecast time period is not sufficiently long to expect all of the location decisions to be made or if there are significant factors inhibiting this shift such as differences in income level or other characteristics of the residential population and employment in "competing" zones. Unfortunately, little is known about how quickly location-choice decisions are made or reevaluated in response to changes in congestion. Similarly, the degree to which travel time and cost determine trip distribution rather than other less tangible characteristics is largely unknown. Careful monitoring of the reasonableness of changes in trip distribution resulting from feedback is therefore recommended.

Research Conclusions and Directions for Future Research

The research conducted in this project identified clear theoretical justification for inclusion of feedback in the traditional four-step modeling process. The research also identified specific regulatory requirements for the incorporation of feedback under certain categories of non-attainment according to the Clean Air Act Amendments of 1990. While designed to represent a series of traveler choices made on the basis of travel times and costs, many sequential modeling processes without feedback produce speeds and travel times as outputs that are not consistent with the speeds and travel times used as inputs to steps earlier in the sequential process. As a result of the research in this study, the value of feedback in the four-step process was recognized not only as necessary to satisfy regulatory requirements, but as a means of representing speeds and travel times more accurately and consistently in the modeling system.

Based on numerous tests of alternative feedback methods using two test-cases, the following specific conclusions were drawn:

- *The implementation of feedback is possible within the existing travel forecasting packages used today.*
- *The implementation of the assignment-distribution feedback can produce different system-wide travel characteristics such as the average speeds and average trip length when there is congestion in the modeled networks. This result suggests that feedback may be essential to accurate forecasts when congestion exists. It also suggests that a recalibration of a model system to observed baseline data is necessary after introduction of feedback.*

- *A recalibrated model system with feedback will generally show less sensitivity of speed to growth in travel than a model system without feedback. The model system with feedback will shift trips away from congested links to the extent possible given the constraints imposed by the modeler.*

- *The Direct Method for feedback, which uses the results of the last iteration directly as input to next iteration, takes significantly longer to converge with greater fluctuations than the other methods that average the results between successive iterations.*

- *Among the feedback methods that average results of each iteration with the results of previous iterations, the tests that were performed showed the methods that use a fixed weight from the results of each iteration (Methods of Successive Averages) have almost the same convergence characteristics as methods that calculate an optimal weight for each iteration (Methods of Optimal Weighting), but with considerably less complexity and with faster execution.*

- *Integrating mode choice in the feedback process can lead to substantial increases in computing time, and in the test cases did not change the transit trips significantly beyond what was produced by an assignment-distribution feedback with assumed person-to-vehicle conversion factors and a full mode choice execution after convergence. If realistic assumptions about the final mode shares and auto occupancies can be obtained prior to execution, a feedback process with integrated mode choice may not be necessary except where transit use is very high and the transit networks are complex.*

- *In all cases, incorporating feedback in the process increased the computational time and storage requirements to produce a forecast. Feedback is complicated and each additional feedback iteration increases the execution time. It also increases the difficulty of understanding/explaining the interrelationships between the transportation improvements and forecasts that result from their implementation.*

The research in this project examined the feasibility and impacts of introducing feedback into the four-step forecasting process. It focused primarily on the assignment-distribution feedback loop required by the 1990 Clean Air Act Amendments and its implementation within existing travel forecasting software. There are a number of other potential feedback options that were not addressed in this effort, and a number of issues arose during the research that should be explored to gain a better understanding of feedback in travel forecasting. These potential research topics include:

- *The impacts of feedback to trip-generation and land-use forecasting,*

- *The incorporation of time-of-day into the feedback process,*

- *The use of impedance functions that include costs and composite impedances,*

- *Further exploration of the Method of Optimal Weighting in complex model systems, and*

- *The accuracy of the feedback process in predicting changes over different lengths of time.*

Another FHWA-sponsored research project is examining the changes in travel characteristics (network speeds, trips, etc.) that arise from incorporating feedback from the transportation models to the land-use forecasting models. The results from this parallel research effort will be available in 1996. Others have examined ways to incorporate measures of forecasting of accessibility into trip generation and time of travel, but the incorporation of accessibility measures should be explored more fully. The test cases chosen for this project did not lend themselves to a detailed analysis of composite impedance functions that include cost, or modes other than auto. More analysis in this area is warranted.

The Method of Optimal Weighting (MOW) also warrants further exploration. This research tested the implementation of MOW in a standard forecasting package (MINUTP) without custom programs. The tests indicated that the MOW method can be implemented using current software, but because of the computational requirements of MOW, special custom programming is required to maximize efficiency and reduce run time. MOW was not explored under a full range of conditions. Further research is warranted to determine when MOW provides clear benefits with respect to convergence and execution time.

The development and validation of both the traditional four-step process and processes with feedback have to date been based upon cross-sectional data for a particular validation year. The true test of feedback is its performance in predicting future conditions when the congestion and other variables change in different proportions throughout a region causing new travel patterns to develop. Examining the stability of the feedback relationships over time should consequently be investigated further by applying a validated feedback process to two base years (1980 and 1990 for example) to see if the feedback process captures the changes in travel patterns that actually occurred over time.

References

Baltimore Metropolitan Council Of Governments (BMC), "Validation Of Baltimore Regional Travel Demand Model," Baltimore Maryland, 1992.

Boyce, D. E., Day, N. D., and McDonald, C., Metropolitan Plan Making: an Analysis of Experience with the Preparation and Evaluation Of Alternative Land Use And Transportation Plans, Regional Science Research Institute, Philadelphia, Pennsylvania, 1970.

Boyce, D.E., Zhang, Y.F., Lupa, M.R, "Introducing Feedback into Four-Step Travel Forecasting Procedure Versus Equilibrium Solution of Combined Model," Transportation Research Record # 1443. Transportation Research Board, Washington D.C. 1994. pp 65-74.

Boyce, D.E., Unpublished Correspondence to COMSIS Corporation, April 24, 1995.

Boyce, D.E., LeBlanc, L.J., Chon, K.S. "Network Equilibrium Models of Urban Location and Travel Choices: A Retrospective Survey". Journal of Regional Science. Volume 28, No. 2, 1988.

Denver Regional Council Of Governments (DRCOG), "Travel Models For Regional And Subregional Planning In The Denver Region," Denver Colorado, 1992.

Euler, G. W., Robertson, H.D. National ITS Program Plan: Volume I, U.S. Department of Transportation, Joint Program Office For Intelligent Transportation Systems, Washington, D.C., March 1995.

Evans, S.P. "Derivation And Analysis Of Some Models For Combining Trip Distribution and Assignment". Transportation Research, Vol 10. pp 37-57. Pergamon Press, 1976

Federal Highway Administration (FHWA), U.S. Department of Transportation, "Documentation of Feedback Procedure," Unpublished Research Memo from Lisa Gion to Chris Fleet and Brian Gardner. September 8, 1994.

Florian, M., EMME/2 User's Manual: Software Release 5.0, Inro Consultants, Montreal, Canada, 1991.

Florian, M., Nguyen, S., Ferland, J. "On The Combined Distribution-Assignment of Traffic". Transportation Science Vol. 9. pp 43-53. 1975.

Horowitz, A.J., "Convergence Of Certain Traffic And Land-Use Equilibrium Assignment Models". Environment and Planning Analytic, 1991 Volume 23. pp 371-383.

Lawton, T.K., Walker, R.E. "Transportation Model Equilibrium - In Practice It's Simple," Paper Presented at the Fourth National Conference of Transportation Planning Methods Applications, Daytona Beach, Florida, April 1993.

Mann, W. "Travel Demand Forecasting Process Used by Ten Large Metropolitan Planning Organizations, Institute of Transportation Engineers, 1993.

Metropolitan Washington Council of Governments (MWCOG), "FY-94 Development Program for MWCOG Travel Forecasting Models, Volume A: Current Applications" Washington, D.C. 1994.

Ortuzar, J.D., Willumsen, L.G., Modeling Transport. Chichester England: John Wiley & Sons, 1990.

Parsons Brinckerhoff Quade & Douglas, Inc.(PBQD), "Review Of Best Practices" Prepared for the Metropolitan Washington Council Of Governments, Washington, D.C., December 1992.

Sheffi, Yosef, Urban Transportation Networks: Equilibrium Analysis With Mathematical Programming Methods, Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 1985.

United States Congress, Clean Air Act Amendments of 1990.

United States Environmental Protection Agency, "Procedures For Emission Inventory Preparation Volume IV: Mobile Sources," USEPA Office of Mobile Sources, Ann Arbor Michigan, 1992.

United States Environmental Protection Agency, "Section 187: VMT Forecasting and Tracking Guidance," January 1992.

United States Environmental Protection Agency. "Criteria and Procedures for Determining Conformity to State or Federal

Implementation Plans of Transportation Plans, Programs, and Projects Funded or Approved Under Title 23 U.S.C. or the Federal Transit Act: Final Rule," November 1993.

U.S. Environmental Protection Agency, User's Guide To Mobile 5a (Mobile Source Emission Factor Model). Report No. Epa-AA-TEB-91-01, Emission Control Technology Division, Test and Evaluation Branch, Ann Arbor, Michigan, 1994.

U.S. District Court for Northern California. Sierra Club v. Metropolitan Transportation Commission, et al., Civil No. C-89-2064-TEH. And Citizens for a Better Environment et al. v. Peter B. Wilson et at., Civil No. C-89-2044-TEH, 1990.

Van Vuren, T., Unpublished Correspondence From the Hague Consulting Group to Larry Seiders, COMSIS Corp., May 30, 1995.

Walker, W.T., Peng, H. "Alternate Methods to Iterate A Regional Travel Simulation Model: Computational Practicality An Accuracy." Paper Presented at the 74th Annual Meeting of the Transportation Research Board, Washington, D.C., January 1995.

1. OVERVIEW

1.1 Project Objectives

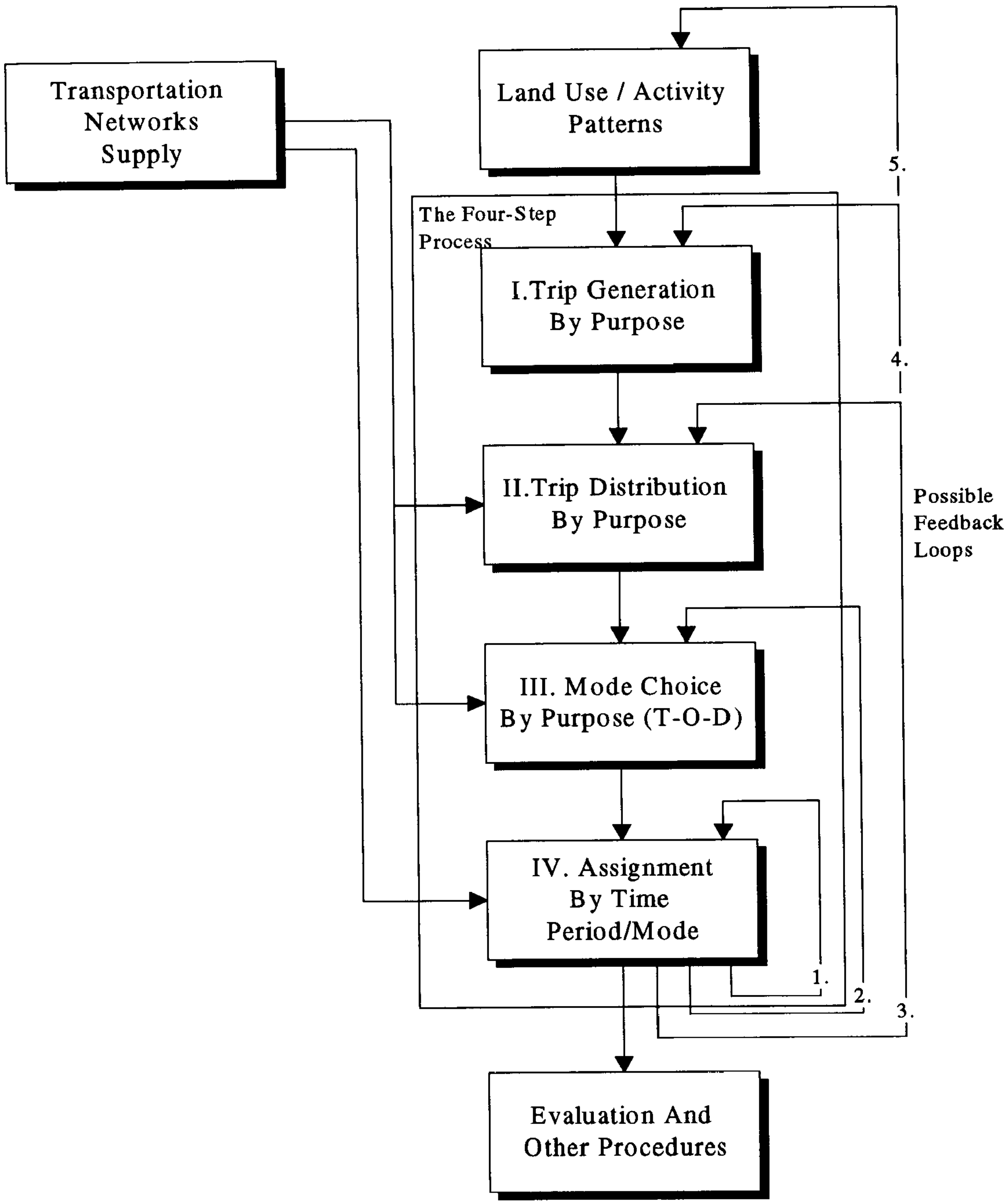
The most common method for producing regional or metropolitan area travel forecasts in the United States is to apply the following four modeling steps sequentially:

- trip generation,
- trip distribution,
- mode choice, and
- route assignment.

This traditional four-step process passes output from one step to the next as input, as illustrated in Figure 1.1. While the process has produced forecast results sufficiently accurate for many types of long-range transportation planning, it is commonly found that some of the outputs of the process are not consistent with inputs to earlier steps. The research undertaken in this project focused on methods to ensure that link speeds used in each step of the travel forecasting process are consistent with the final speeds estimated in the final step of the process. A variety of methods for introducing "feedback" into the process (reintroducing output of one step as input to a previous step) were explored and guidance was developed on when and how to incorporate feedback into the four-step modeling process. Figure 1.1 illustrates four possible ways in which feedback can be provided in the four-step process and one additional way that feedback can be accomplished to the forecasting of land-use and activity patterns.

The exploration of methods for introducing feedback into the traditional four-step travel forecasting process is not new. Methods implementing feedback have been used for planning studies in major U.S. metropolitan areas for at least twenty-five years (Boyce et al., 1970; Boyce, et al., 1994; Lawton and Walker, 1993; BMC, 1992; DRCOG, 1992; MWCOG, 1994; PBQD, 1992; Mann, 1993). But introducing feedback using currently available travel forecasting software can be complex, is generally cumbersome, often requires lengthy execution times, and is prone to significant pitfalls and errors. As a result, few modelers have chosen to pursue implementation of feedback in regional or metropolitan area models despite some of the theoretical and obvious intuitive justifications for doing so. This research effort was initiated

Figure 1.1: Feedback Locations within the Four-Step Process



Feedback Locations:

1. Capacity-constrained equilibrium assignment
2. Congested times as inputs to mode split
3. Congested times or composite impedances as inputs to trip distribution
4. Accessibility factors in trip generation
5. Land use - transportation interaction

because the need for better emissions estimates may require modelers for major metropolitan areas to incorporate feedback in a way that will produce consistent use of travel speeds throughout the modeling process. Another related motivation is the desire to better capture the effects of congestion on traveler choice behavior and the benefits of congestion management strategies in reducing delay.

The Federal Highway Administration (FHWA) sponsored this research effort to support states and metropolitan planning organizations in their responses to the new regulatory requirements for emissions modeling and to support the continuing improvement of travel demand modeling. To meet those basic objectives, the research was designed to address the following questions:

- Does feedback make a difference in the results of a four-step modeling process and if so, under what conditions?
- What methods are available for feedback and what are the advantages and disadvantages of each?
- What criteria should be used to determine when feedback has successfully resulted in consistency of speeds in the modeling process?
- What guidance can be provided to modelers who choose to undertake the introduction of feedback?

Central to this research effort was the application of a variety of feedback methods within two case-study model systems: the regional travel forecasting systems for Memphis, Tennessee and Salt Lake City, Utah. These model systems were chosen because they were readily available to the research team and because they could be used to reflect a range of levels of congestion by manipulating the baseline conditions representing the input to the model system (the transportation network and the land use forecast). The performance of the alternative methods for implementing feedback and the variety of methods for assessing convergence could be tested in response to the full range of travel conditions. From these tests, the research team was able to determine when feedback is likely to make a significant difference in forecast results, which methods are most likely to produce improved accuracy under different conditions, and the overall resource requirements of each method.

1.2 Methods of Introducing Feedback

Numerous researchers and planning practitioners have experienced difficulty achieving convergence in a feedback process when a Direct Method of feedback is used: the output of assignment is used directly, unaltered, as input for a previous step in the modeling process. A number of alternatives to the Direct Method have been identified by previous researchers and practitioners as ways to reduce processing time and assure convergence. All of the methods represent alternatives for using information from all previous iterations to move the next iteration toward a convergent solution. The methods use somewhat different approaches either in the assignment algorithm or in the method for combining results of previous iterations to produce new input values. The four alternative methods chosen for application in this research are as follows:

- Method of Successive Averages with Equilibrium Assignment (MSA-EQA) - provides equal weight to each previous iteration's equilibrium assignment results.

- Method of Successive Averages with All-or-Nothing Assignment (MSA-AON) - same as MSA, but each assignment is made on a single best-path basis.

- Method of Optimal Weighting with Equilibrium Assignment (MOW-EQA) - computes as optimal weighting for each iteration's equilibrium assignment.

- Method of Optimal Weighting with All-or-Nothing Assignment (MOW-AON) - same as MOW-EQA but each assignment is made on a single best-path basis.

For all four of these alternative methods, the volumes from previous iterations are averaged with the volumes from the most recent assignment and new input speeds are determined based upon the averaged volumes. The speeds from previous iterations are not averaged directly because of the non-linear relationship between volume, capacity, and speed. All of these methods address the way in which output from assignment is manipulated prior to reintroduction as input to a previous step. The applications of any one of the alternative approaches is basically the same regardless of where in the four-step process the assignment data are being fed back.

1.3 Significant Findings

Some of the significant findings of this research effort are:

- The implementation of feedback is possible within the existing travel forecasting packages used today.

- The implementation of the assignment-distribution feedback can produce different system-wide travel characteristics such as the average speeds and average trip length when there is congestion in the modeled networks. This result suggests that feedback may be essential to accurate forecasts when congestion exists. It also suggests that a recalibration of a model system to observed baseline data is necessary after introduction of feedback.

- A recalibrated model system with feedback will generally show less sensitivity of speed to growth in travel than a model system without feedback. The model system with feedback will shift trips away from congested links to the extent possible given the constraints imposed by the modeler.

- The Direct Method for feedback, which uses the results of the last iteration directly as input to next iteration, does not always converge to an equilibrium solution. When it does converge, it takes significantly longer and with greater fluctuation than the other methods that average the results between successive iterations.

- Among the feedback methods that average results of each iteration with the results of previous iterations, the tests that were performed showed the methods that use a fixed weight from the results of each iteration (Method of Successive Averages) have almost the same convergence characteristics as methods that calculate an optimal weight for each iteration (Method of Optimal Weighting), but with considerably less complexity and with faster execution.

- Integrating mode choice in the feedback process can lead to substantial increases in computing time, and in the test cases did not change the transit trips significantly beyond what was produced by an assignment-distribution feedback with assumed person-to-vehicle conversion factors and a full mode choice execution after convergence. If realistic assumptions about the final mode shares and auto occupancies can be obtained prior to execution, a feedback process with integrated mode choice may not be necessary except where transit use is very high and the transit networks are complex.

- In all cases, incorporating feedback in the process increased the computational time and storage requirements to produce a forecast. Feedback is complicated and each additional feedback iteration increases the execution time. It also increases the difficulty of understanding/explaining the interrelationships between the transportation improvements and forecasts that result from their implementation.

1.4 Topics for Future Research

The research in this project examined the feasibility and impacts of introducing feedback into the four-step forecasting process. It focused primarily on the assignment-distribution feedback loop required by the 1990 Clean Air Act Amendments and its implementation within existing travel forecasting software. There are a number of other potential feedback options that were not addressed in this effort, and a number of issues arose during the research that should be explored to gain a better understanding of feedback in travel forecasting. These potential research topics include:

- The impacts of feedback to trip-generation and land-use forecasting,
- The incorporation of time-of-day into the feedback process,
- The use of impedance functions that include costs and composite impedances,
- Further exploration of the Method of Optimal Weighting in complex model systems, and
- The accuracy of the feedback process in predicting changes over different lengths of time.

Another FHWA-sponsored research project is examining the changes in travel characteristics (network speeds, trips, etc.) that arise from incorporating feedback from the transportation models to the land-use forecasting models. Others have examined ways to incorporate measures of accessibility into trip generation and time of travel, but the incorporation of accessibility measures should be explored more fully. The test cases chosen for this project did not lend themselves to a detailed analysis of composite impedance functions that include cost, or modes other than auto. More analysis in this area is warranted.

The Method of Optimal Weighting (MOW) also warrants further exploration. This research tested the implementation of MOW in a standard forecasting package (MINUTP) without custom programs. The tests indicated that the MOW method can be implemented using current software, but because of the computational requirements of MOW, special custom programming is required to maximize efficiency and reduce run time. MOW was not explored under a full range of conditions. Further research is warranted to determine when MOW provides clear benefits with respect to convergence and execution time.

The development and validation of both the traditional four-step process and processes with feedback have, to date, been based upon cross-sectional data for a particular validation year. The true test of feedback is its performance in predicting future conditions when the congestion and other variables change in different proportions throughout a region causing new travel patterns to develop. Examining the stability of the feedback relationships over time should consequently be investigated further by applying a validated feedback process to two base years (1980 and 1990 for example) to see if the feedback process captures the changes in travel patterns that actually occurred over time.

1.5 Report Contents

The remainder of this report provides guidance on when, where, and how to implement the basic feedback mechanisms within the four-step travel forecasting process. It also examines a number of issues and concerns that the practitioner should be aware of when implementation of feedback is being considered.

Chapter 2 provides guidance on when and where feedback should be implemented. The chapter contains a brief description of the regulatory requirements for feedback in travel forecasting (more detail is provided in Appendix A). The 1990 CAAA and the procedures that must be followed for its conformity analysis are the main source of regulations for feedback in travel forecasting. If an area is in serious air quality non-attainment or worse, then feedback must be considered. Other conditions may also warrant the investigation of feedback.

Chapter 3 describes the mechanics of how to implement feedback within the four-step travel forecasting process. A Generic Feedback Framework developed for the project is defined and possible feedback methods within this framework are then described. A number of additional attributes and features that any feedback implementation should have are also explained.

Chapter 4 provides a detailed examination of the results from the application of feedback for two test cases: Memphis, Tennessee and Salt Lake City, Utah. The alternative methods for applying feedback were tested under a variety network configurations and different levels of congestion. The incorporation of mode choice in the feedback process is also examined in the chapter.

Chapter 5 provides guidance in the application of feedback for those situations in which feedback is warranted. The chapter addresses many of the complex issues that one must face in implementing feedback and identifies the most common pitfalls faced in practical application.

2. WHEN AND WHERE SHOULD FEEDBACK BE APPLIED

The first step in designing the feedback mechanisms for an urban region's modeling system is determining if, when, and where feedback should be used. Careful consideration should be given to whether feedback is needed in the particular area that is being modeled, and if so, where in the four-step planning process feedback may be warranted. This section provides a process, or feedback decision tree, for determining when feedback is necessary, and where it should be applied. The factors and key indicators found to influence the need for feedback are described and a feedback decision hierarchy is provided

2.1 Factors and Key-Indicators of the Need for Feedback

The factors influencing the need for feedback have been determined based upon recent regulatory requirements and results of test care applications of feedback for Memphis, Tennessee, and Salt Lake City, Utah. Because one of the primary goals of feedback is to obtain similar speeds and travel times from the final assignment as those used in earlier modeling steps, the key factors are characteristics that impact the changes in times/speeds and how they vary across an area. These factors are shown in Table 2.1 and discussed in the sections that follow.

Table 2.1 Factors Determining the Need for Feedback

1.	Air quality non-attainment status
2.	Region size/density
3.	Anticipated future congestion measured by Percent Delay or V/C Ratio
4.	Concentrations of future congestion in sub-areas or on selected facilities
5.	Anticipated levels of other mode services (HOV, Transit) and their anticipated use region-wide.
6.	Anticipated concentrations of other mode services and use to specific locations or within corridors.
7.	Mix of trips by purpose during congested periods.

Air Quality Non-Attainment Status: The Clean Air Act Amendments of 1990 state that if a region is classified as "Severe Non-Attainment" or worse, it must have a network-based transportation model with the following capabilities:

- A capacity sensitive assignment methodology for peak-hour or peak-period traffic assignments *(feedback within assignment).*
- Methods to estimate traffic speeds and delays that are sensitive to traffic volumes in the network model.
- Zone-to-zone travel times used to distribute trips between origin and destination pairs must be in reasonable agreement with the travel times that result from the process of assignment of trips to network links (*assignment to trip distribution feedback).*

Other feedback features required or strongly encouraged when transit use is significant are: the use of congestion times in transit mode split calculations, time-to-day sensitivity, sensitivity to transportation impacts on land use, and accessibility impacts on trip generation. Any serious or worse non-attainment area must demonstrate consistency between the times used for distribution with final assignment or introduce feedback. For areas with low levels of anticipated congestion, it may suffice to show the relatively low impacts of feedback on the speeds of VMT values. Appendix A provides greater detail concerning the regulatory requirements for feedback. A summary of the implications of the Clean Air Act Amendments for feedback in all categories of nonattainment is provided in Table 2.2.

Introduction of feedback may also be appropriate for areas that are not classified as serious non-attainment. Doing so may better capture the impacts of congestion on travel and the benefits of demand management and congestion management measures or provide a defense against litigation over the conformity findings.

Region Size/Density: The size of an area is related to many of the attributes that contribute to the impacts of feedback in forecasting. A smaller urban area such as Memphis typically has fewer zones, less congestion, lower percentages using transit, and less sophisticated travel forecasting applications. Many small urban areas, for example, use a three-step travel forecasting procedure

Table 2.2: Environmental Indicators Determining Feedback Requirements

	Urban Area Population		
NAAQ Status	**Less than 50,000**	**50,000 to 200,000**	**200,000+**
Extreme, Severe, Serious	Not an Urban Area. Travel forecasting models unlikely.	Network based models with speed consistency required. No TMA. Feedback should be considered based on congestion levels	Network-based models with speed consistency required. TMAs & CMS also needed. Feedback must be considered.
Moderate, Marginal	Conformity and planning responsibility of State. Network model unlikely	MPO and State cooperatively determine responsibilities. Network models not required. Congestion strategies not required. If models do exist, Feedback may be desirable based upon congestion levels	Network models that explicitly address impacts of "land use and transportation infrastructure on VMT, traffic speeds and congestion." TMA's & CMS still needed. Feedback should be considered based on congestion levels
Maintenance	Conformity and planning responsibility of State. Network models unlikely	See Above. If models do exist, Feedback may be desirable based upon congestion levels	See Above. If models do exist, Feedback may be desirable based upon congestion levels
Attainment	Simplified planning procedures allowed.	Simplified planning procedures allowed.	See Above. If models do exist, Feedback may be desirable based upon congestion levels

consisting of vehicle trip generation, trip distribution and assignment. For these applications, the trip generation step produces vehicle trips directly or a fixed set of factors are used to convert person trips by purpose to vehicle trips. Areas under 50,000 have much less stringent planning and analysis requirements as well. The number and size of the zones may also impact the stability of the feedback, as indicated in Section 5.4.

Anticipated Future Congestion Measured by Percent Delay or Volume/Capacity Ratio: The results from the test cases for Memphis and Salt Lake City clearly illustrate the relationship between congestion and the impacts of feedback. Table 2.3 and Figures 2.1 and 2.2 illustrate the relationship between congestion in a model network (as represented by Percent Delay and average V/C ratio) and the effects of feedback prior to recalibration of a model system. Percent Delay is the percent of travel time in a region that is above what would be experienced under free-flow conditions and the V/C ratio is the ratio of the peak-hour volume on all links to the one-hour capacity of all links. The table and figures demonstrate that as congestion increases in a model network, feedback results in greater change in average system-wide speed, trip length and trip time. The trends are consistent and clear: average trip length decreases, average trip time decreases, and average speed increases. The percent change in average trip length decreases then seems to stabilize at around -6.0 percent.

Based upon the figures the change in average speed (percent change due to feedback greater than five or six percent) seems to become significant at around a 20 percent Delay or a V/C ratio of 0.75. These become the thresholds for the first check for the need for feedback between distribution and assignment as illustrated in Table 2.4.

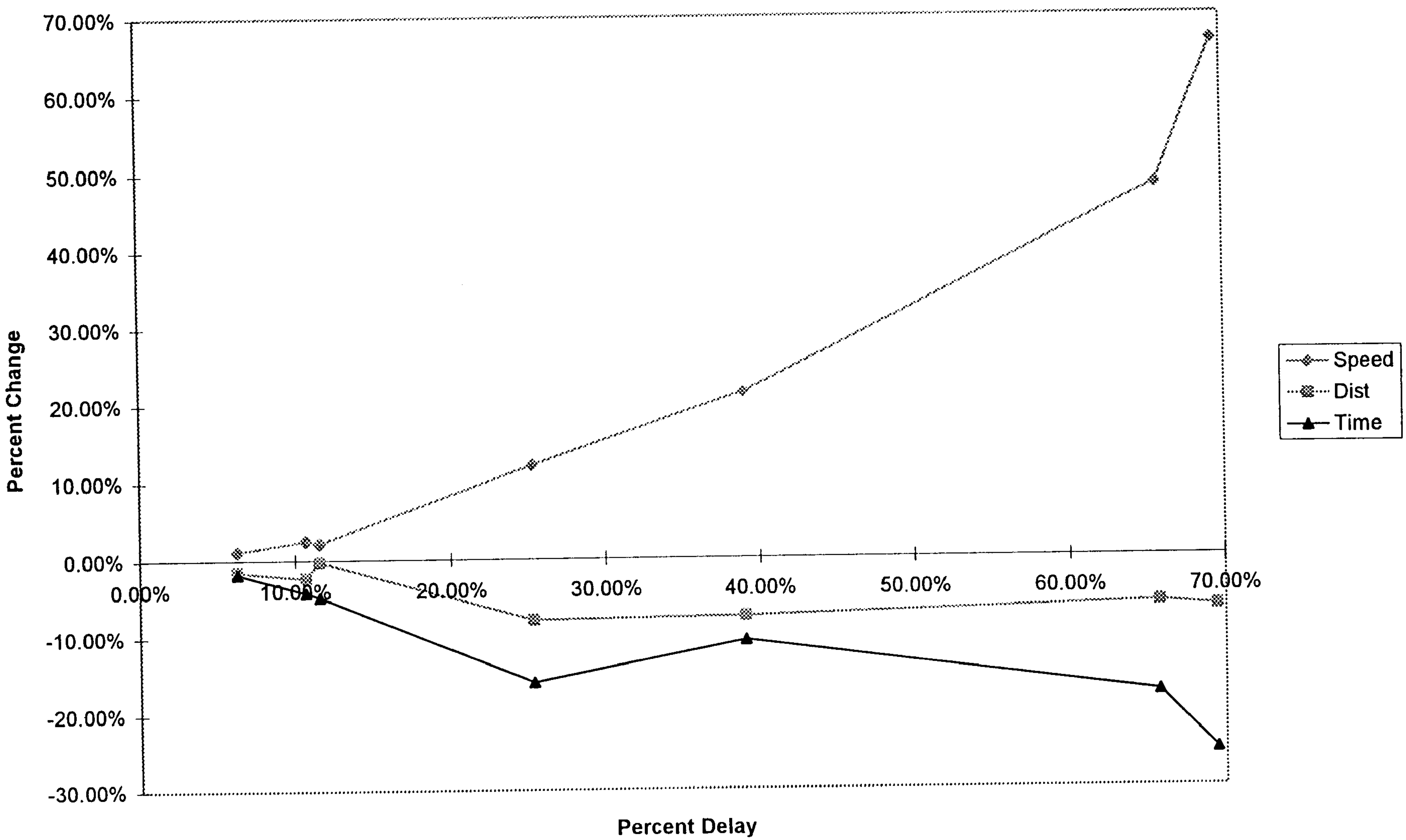
Because of the strong relationships, these measures should be used as key-indicators for the need to introduce feedback in a travel forecasting process. Their values should be obtained from the existing No-Feedback forecasting application for the region, or from the VMT estimation procedures provided by the "Section 187 VMT Forecasting and Tracking Guidance" (U.S. EPA, January 1992), which provides methods to estimate future VMT based upon the HPMS data for those areas contemplating the development of new models.

Table 2.3: Comparison of Congestion Indicators and Change due to Feedback

Analysis of Thresholds values										
			Vehicle Hours				% Change: No-Feedback to Feedback			
Case	Assigned Trips	Vehicle Distance	Free Flow	Congested	Delay	% Delay	Average V/C	Speed	Dist	Time
Memphis Base	2,358,348	15,824,774	356,595	380,371	23,776	6.25%	0.50	1.13%	-1.47%	-1.79%
Memphis Uniform 25%	2,933,373	19,745,648	448,741	502,256	53,515	10.65%	0.62	2.46%	-2.29%	-4.17%
Memphis Radial 25%	2,923,865	20,021,850	454,086	513,391	59,305	11.55%	0.63	2.15%	-0.23%	-4.72%
Memphis Uniform 75%	4,082,381	27,737,426	637,541	853,165	215,624	25.27%	0.87	12.10%	-7.84%	-15.90%
Salt Lake Base	2,524,289	17,801,550	493,355	808,940	315,585	39.01%	0.98	21.34%	-7.50%	-10.58%
Salt Lake Uniform 25%	3,186,942	24,092,624	668,779	1,950,718	1,281,939	65.72%	1.24	48.23%	-5.96%	-17.51%
Salt Lake Radial 25%	3,178,978	24,353,010	672,780	2,204,513	1,531,734	69.48%	1.24	66.64%	-6.52%	-25.07%
Memphis New Facility	2,360,747	1,627,475	355,946	375,979	20,034	5.33%	0.46	0.73%	-0.32%	-1.24%
Salt Lake New Facility	2,556,119	19,098,413	519,512	861,423	341,911	39.69%	0.95	-8.46%	-1.85%	6.72%

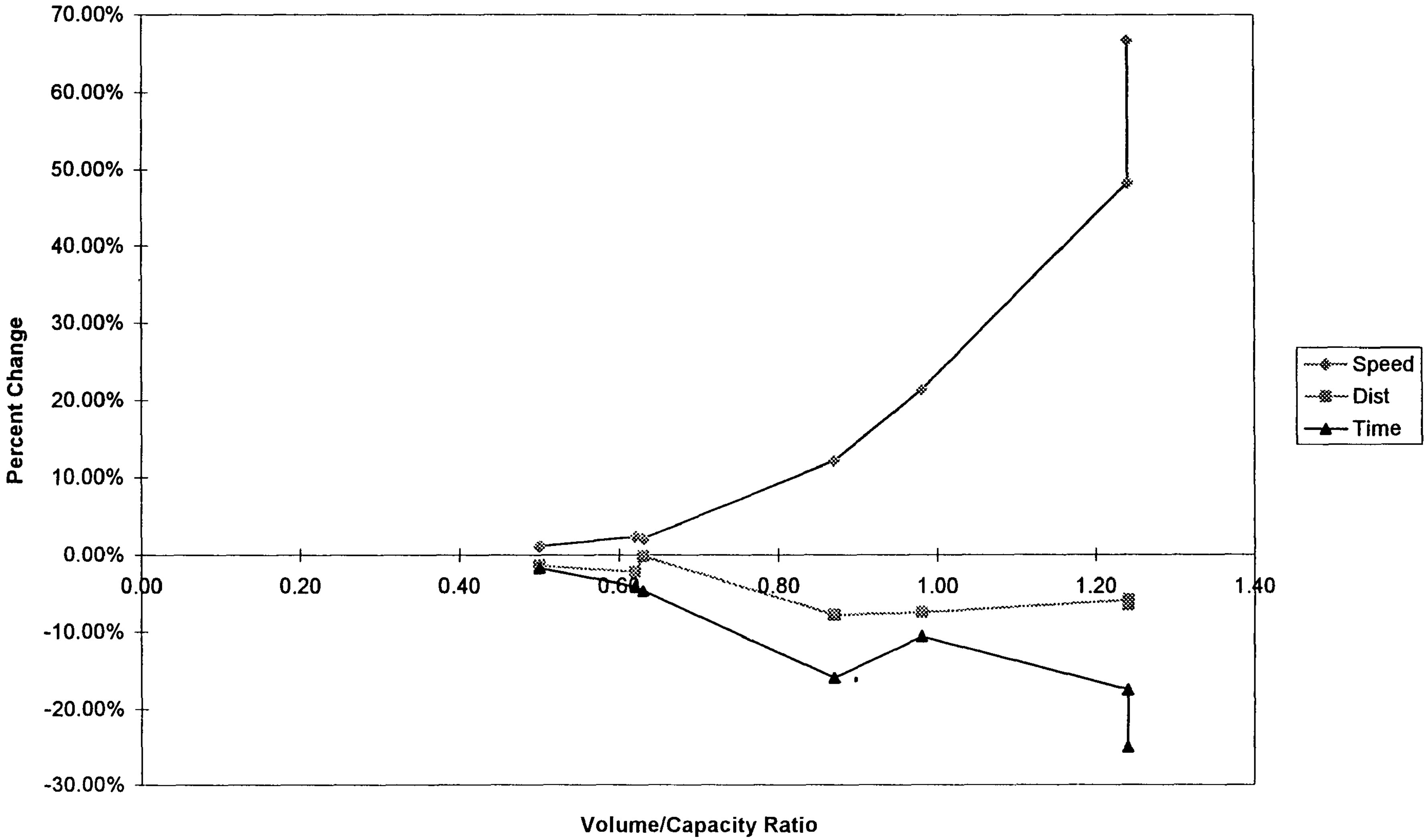
Note: The feedback method reported is the Method of Successive Averages with Equilibrium Assignment (MSA-EQA)

Figure 2.1: Change in System Statistics due to Feedback* as a Function of Congestion



Note: The feedback method reported is the Method of Successive Averages with Equilibrium Assignment (MSA-EQA)

Figure 2.2 : Change in System Statistics due to Feedback* as a Function of Congestion



Note: The feedback method reported is the Method of Successive Averages with Equilibrium Assignment (MSA-EQA)

Table 2.4: Guidance on Appropriate Use of Feedback Mechanisms

System % Delay	System V/C Ratio	Number of zones/other considerations	Mechanism
<=20%	<=.75	All sizes	Equilibrium Assignment with checks on before and after speeds/times
>=20%	>=.75	<=300 to 400	Assignment-Distribution feedback at a minimum. MSA with equilibrium assignment recommended.
>>20%	>>.75	>= 1000 Assignment exec. time >> distribution exec. time	Possible significant time savings with the use of Evans procedure and/or AON assignment. Additional zones provide more distributed AON assignments.
>>20%	>>.75	Transit System Exists throughout area	Incorporate transit mode split and skims in feedback mechanism
>> indicates much greater than actual value, where new mechanism required is subjective.			

Anticipated Concentrated of Future Congestion in Sub-areas or on Selected Facilities: As will be demonstrated in later sections describing the results of the test cases and sensitivity analyses, feedback can show significant differences in its impacts by location and facility type. Thus, the future conditions for a modeled network should also be examined by area type and major jurisdiction to ensure that sub-areas do not have characteristics that impact the pattern of impedances between origins and destinations. The same criteria of Percent Delay greater than 20 percent or V/C ratio greater than 0.75 should be used.

Anticipated Levels of Other Mode Services (HOV, Transit): Feedback may have significant impact on the predicted use of alternative modes of travel such as HOV and transit. The Metropolitan Washington Council of Governments, for example, reported a decrease in the base-year forecasts of 20 percent for HOV use and 11 percent for auto-access transit trips when feedback was introduced for the home-based-work trips (MWCOG, 1994). This is primarily a function of the transit and HOV trips providing a significant amount of the work-trip travel and not being part of the impedance calculations for trip distribution. When feedback was introduced, trips were re-oriented away from congested links and corridors (the primary HOV and transit markets) and speeds improved in general for the SOV mode. Transit had a 13 percent share and HOV a 20 percent share for the work trips in the Washington, D.C. region in the 1990 model year.

The Clean Air Act conformity guidance also calls for transit to be included in the feedback mechanisms when its use is "significant." To test the impact of the transit share it is recommended that an assignment be made assuming all of the peak trips are made in private vehicles. If this causes noticeable changes in speed and travel times at the system-wide level (greater than 2 to 3 percent), then feedback is warranted with transit incorporated in the feedback loop.

Anticipated Concentrations of Other Mode Services and Use to Specific Locations or Within Corridors: The impact of alternative models is seen more in the distribution and travel times to specific destinations, and/or corridors than on a system-wide level. In cases where the current or anticipated use of alternative modes is high, mode choice should be incorporated in the feedback process. If substantial time and cost savings are also provided then composite impedances need to be investigated as well.

Mix of Trips by Purpose during Congested Periods: The mix of trips during the congested periods of the day should determine the trip purposes for which feedback should be investigated. The test cases and research for this effort examined feedback for all trip purposes using daily assignments. Research should address the relationship between time-of-travel, trip purpose, and travel times with feedback. If the Percent Delay and V/C conditions are met, feedback should be implemented for the work-related trips at a minimum. The other trip purposes should be examined for their percentage of peak travel (impact on the peak conditions) and their percentage of travel made in the peak (sensitivity to congestion).

2.2 Feedback Decision Hierarchy

The Feedback Decision Hierarchy relates the possible feedback mechanisms (discussed in detail in Chapter 3) and the locations for introducing feedback in the four-step process to the key factors and indicators. As conditions become more severe the hierarchy increasingly adds more complex feedback mechanisms and loops. The potential feedback mechanisms discussed in the hierarchy are:

- **Equilibrium assignment only (multiple A-O-N assignments) with a check on input and output speeds/times.** The simplest form of feedback is capacity constrained equilibrium assignment. Equilibrium assignment iterations should be allowed to continue until convergence is reached. Equilibrium assignment is recommended as the only necessary form of feedback for areas with anticipated low levels of congestion.

- **Feedback from Assignment to Trip Distribution using Method of Successive Averages (MSA) with Equilibrium Assignment and no mode split or mode split after final equilibrium in assignment has been reached.** This is recommended for areas with congestion levels that warrant feedback but with low anticipated transit use (See steps 3 and 4). Equilibrium assignment feedback works well in small to medium areas (fewer zones) with medium congestion levels. Equilibrium assignment is likely in these cases to reach convergence in few iterations, and be relatively fast with respect to the other steps (trip distribution).

- **Method of Optimal Weighting (MOW) with Equilibrium Assignment and no mode split, or mode split after final equilibrium in assignment has been reached.** As stated MOW-EQA is a method that searches for the optimum weights to use when averaging each iteration solution with the existing overall solution. Some of the considerations for its use are discussed in Chapter 3 and 4. It requires extra computation for each iteration to obtain the optimum weight, but has been shown to reach convergence much faster in highly congested networks. MOW should be considered when the execution time for each pass becomes a concern. Larger areas with low transit use may consider this approach.

- **Method of Optimal Weighing (MOW) with A-O-N Assignment.** In areas with many zones (1000+), severe congestion, and where assignment takes significantly more time than trip distribution, it may be appropriate to use A-O-N assignment for each iteration. This has been shown in Philadelphia to converge rapidly and saves considerable execution time (Walker and Peng, 1995).

- **The above, incorporating mode split within each iteration of the distribution-assignment process but not producing new transit skims.** This is appropriate when incorporating transit is warranted, yet the majority of the transit service operates either on exclusive right of way or at speeds not likely to be changed by the anticipated congestion levels of the highway system. The later can occur in urban settings where the bus travel times are dominated by loading and unloading of passengers.

- **The above, incorporating updates of both the transit travel time skims and mode choice.** Where much of the transit service operates in mixed flow and is therefore impacted by the changes in times, it may be necessary to incorporate full transit analysis in each step. This may also include the calculation of composite impedances. In these instances the execution time of each loop may become excessive and the incorporation of MOW may need to be investigated due to its faster convergence.

The Feedback Decision Hierarchy is summarized in Table 2.5.

Table 2.5: Feedback Decision Hierarchy

Step	Description
1	DETERMINE IF ENVIRONMENTAL CONDITIONS REQUIRE FEEDBACK. ▪ Severe Or Worse — Feedback (yes) ▪ 200,000+ — Feedback (yes)
2	ESTIMATE THE SYSTEMWIDE PERCENT DELAY AND VOLUME/CAPACITY RATIO. ▪ Forecast anticipated future delay. ▪ Select base mechanism for implementing feedback from Table 2.5 % Delay > 20% — Feedback (yes) V/C Ratio > .75 — Feedback (yes)
3	LOCAL CONCENTRATIONS OF SEVERE CONGESTION IN SUB-AREAS OR CORRIDORS? ▪ Plot network highlighting links with % Delay greater than 20%. ▪ Plot network highlighting links with Volume/Capacity ratio greater than .75. ▪ For each zone estimate % delay for origins and plot. ▪ Repeat zonal % delay calculations for destinations and plot. ▪ Examine the four plots for concentrations where the congestion exceeds the levels shown in Table V.2.2-2. ▪ If concentrations found implement appropriate feedback mechanism.
4	ASSESS REGION-WIDE TRANSIT AND HOV USE. ▪ If congestion levels are severe : incorporate transit (See Table 2.4). ▪ If congestion levels are moderate : assign all trips to network assuming no transit use and calculate changes in system speeds and times. If noticeable changes are observed at the system level (greater than 2 to 3%) then transit feedback will impact the final solutions. ▪ Test for composite impedance incorporation: (1) Are transit or HOV use levels significant: (2) Are travel time savings on alternative modes noticeable. If greater than 20% savings for users then presume they are significant and investigate composite impedances.
5	REVIEW THE ANTICIPATED FUTURE PLANS AND CONDITIONS FOR SIGNIFICANT TRANSIT SERVICE AND USE IN SUB-AREAS, OR CORRIDORS. ▪ Consider feedback if use to a specific locations (CBD), and travel time savings by the alternative modes is also significant (equivalent to 20% delay)?
6	ASSESS MIX OF TRIPS DURING CONGESTED PERIODS BY PURPOSE. ▪ For each trip purpose the current % of trips made in the peak congested periods. ▪ For each time period the current % of trips made for each purpose. ▪ Examine future congestion levels for potential of peak spreading (major shift in V/C and greater than 1). ▪ If peak and offpeak travel times change differently then examine feedback by purpose.

3. IMPLEMENTATION OF FEEDBACK

This chapter provides a description of how to implement feedback in a production environment. It first provides a brief introduction to what feedback is and why it should be performed followed by an explanation of some of its basic concepts. The chapter then describes a generic feedback framework developed for this project, the alternative feedback methods, and additional features that should be included in any feedback implementation.

3.1 What is Feedback and Why do it?

As graphically illustrated in Figure 3.1, travel forecasting represents an attempt to capture the interactions between and the travel that results from:

- the land use-socioeconomic patterns,
- the supply of transportation and its price, and
- activity patterns of people and goods.

The land use and socio-economic patterns determine where people are and where they can go. The supply of transportation determines how they may get there and at what cost. Activity patterns describe the need for travel and its constraints (when, additional stops, physical needs, etc). As highlighted in Figure 3.2 the traditional four-step travel forecasting process of trip generation, trip distribution, mode choice, and assignment has generally been applied sequentially with the outputs of each step becoming the inputs to the next step. This assumes that many of the interactions and interdependencies found in Figure 3.1 are addressed outside the mathematical model's formal equations. Examples include:

- The impact of additional traffic on travel times of a road segment - trip distribution requires the travel times as inputs and this is often addressed by using estimated "loaded" speeds for trip distribution.

Figure 3.1: Interrelationships of Travel Demand

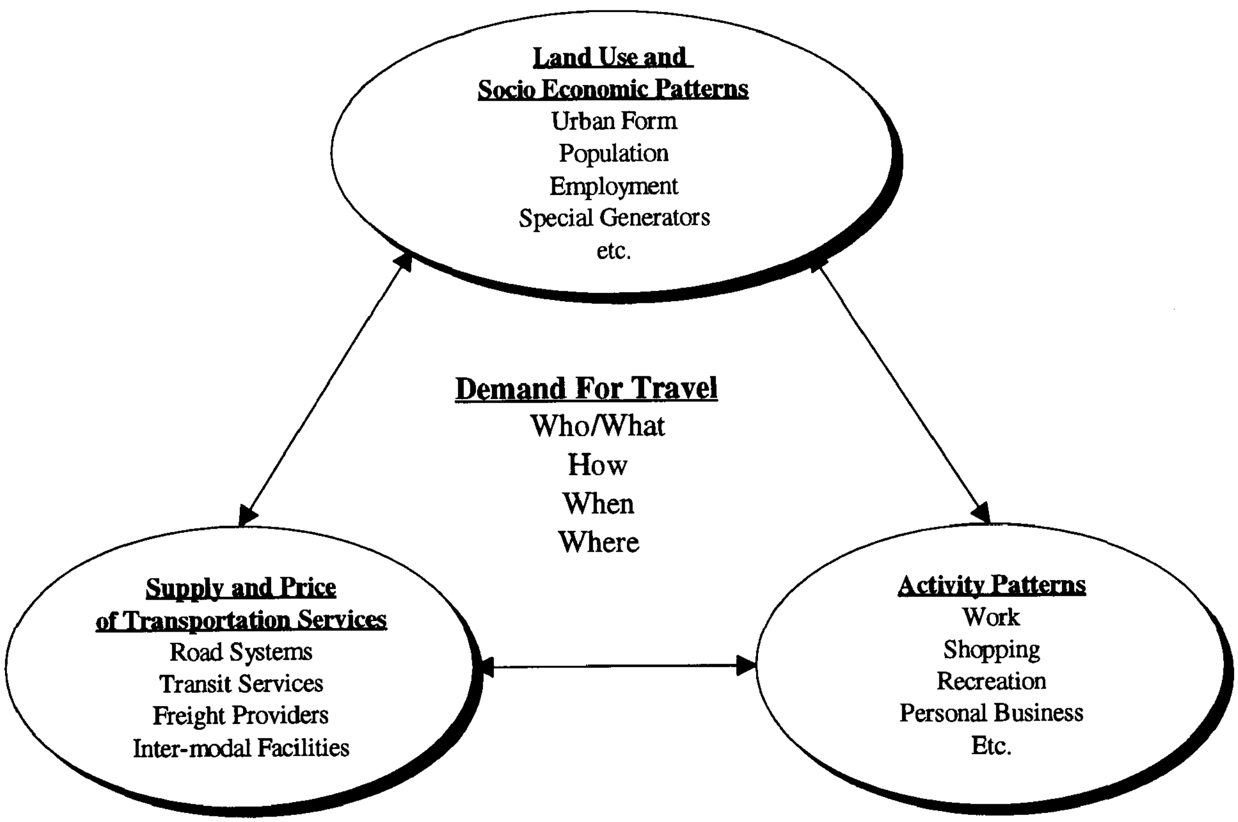
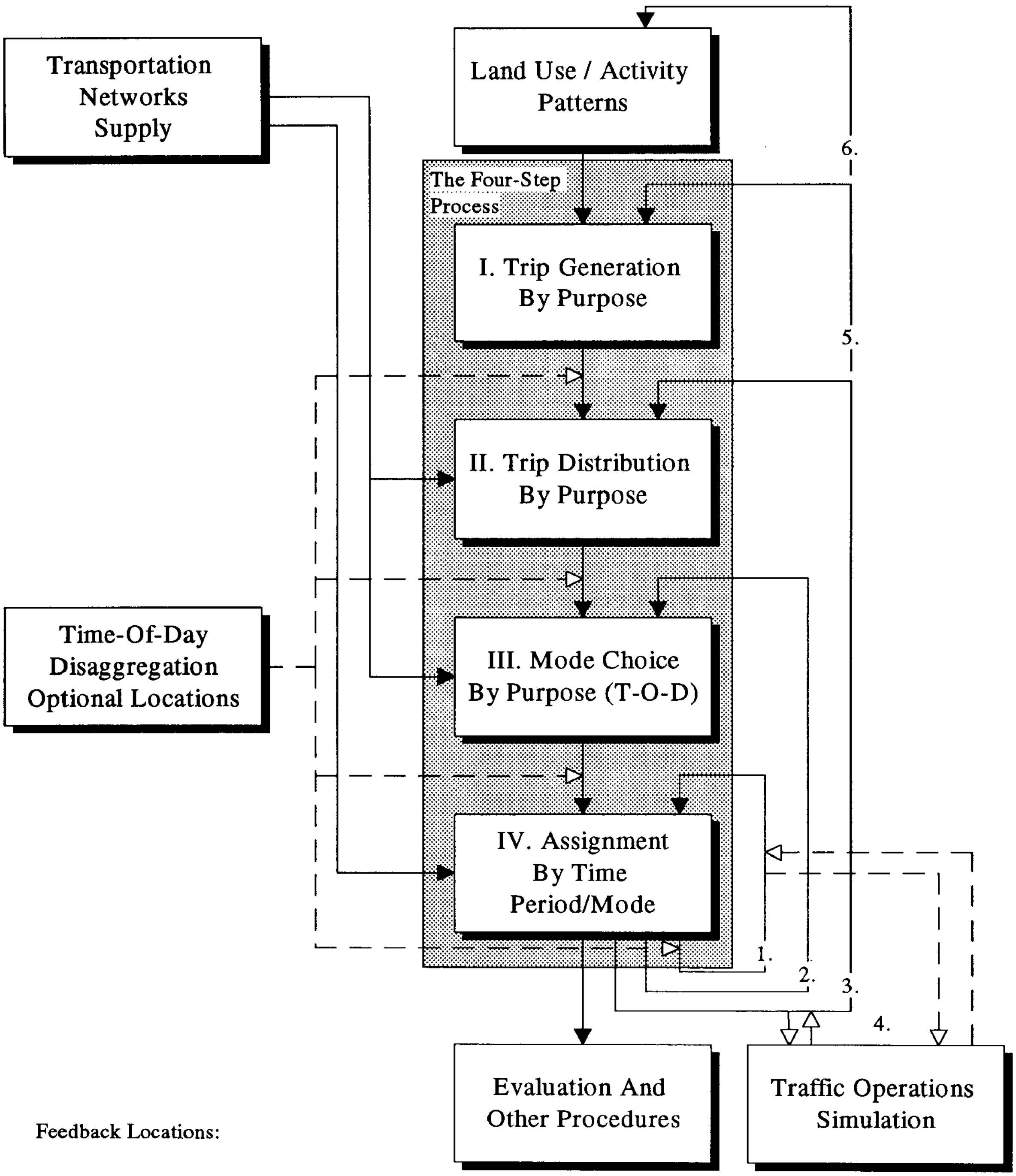


Figure 3.2: Feedback Locations Within the Four Step Process



Feedback Locations:

1. Capacity constrained equilibrium assignment w/wo peak spreading
2. Congested times as inputs to mode split
3. Congested times/ composite impedances as inputs to trip distribution
4. Traffic Operations Simulation Models
5. Accessibility factors in trip generation (Induced Demand)
6. Land use - transportation interaction

1,2,3,4,5,6 : Full feedback

Applications will vary by mode, time period and purpose where feedback is incorporated .

- The impact of the transit mode share on background traffic and congestion - Base auto occupancies and mode split values are often assumed either at the regional or corridor level.

- The transportation/land use interaction - base forecasts of the land use and socio-economic zonal data are usually prepared using "professional judgment" to account for the interaction of transportation and land use. These usually do not vary when alternative transportation systems are considered.

- The impact of congestion on the time-of-day when travel occurs or the activities that may be undertaken.

- Other interactions of the transportation system on behavior such as the impacts of congestion on trip chaining and thus the generation of trips by purpose the effects of accessibility to activities within a reasonable travel time/distance on trip generation, the impacts of congestion on the regional economy, etc.

Feedback by one definition is:

> Using the results of one step in the modeling process to recalculate a previous step. For example, the link volumes from **traffic assignment** can (and should) be used to recalculate first travel speeds and then **trip distribution**, because the first pass through trip distribution employs only an approximation of link speeds. (Harvey and Deakin, 1993, page A-8).

The goal in implementing feedback is to provide a heuristic within the four-step process for reaching an overall "equilibrium" with the forecasting system. An alternate approach to implementing feedback mechanisms between the steps of the four-step process is to develop combined or simultaneous models (see Ortuzar and Willumsen, 1990; Sheffi, 1985). Elements of the "combined" approach are now being incorporated into the available transportation forecasting packages such as EMME/2, MINUTP, and TRANPLAN. In the past, these approaches required additional software, computing capacity, and technical modeling complexity that made their application difficult. Because the "combined" approach has not been adopted widely in practice, the research in this project was focused on the feedback mechanisms within the traditional four-step process.

The possible locations for feedback within the four-step modeling process are illustrated in Figure 3.2. As indicated in the figure, feedback may be introduced in a number of different locations in the traditional four-step process some of which include:

- Introduction of capacity constrained speeds for equilibrium assignment (1)[1].
- Using congested speeds/times in mode choice (2).
- Using congested speeds/times as inputs to trip distribution (3).
- Incorporating the speed/times for all modes in trip distribution using composite impedances (3).
- Connections to traffic simulation models to better represent detailed traffic operations within the modeling process (4)[2].
- Accounting for the impacts of accessibility in trip generation (5).
- Incorporating accessibility into forecasts of land use and population (6).

Feedback mechanisms may also be applied for different trip purposes and/or time periods. The research for this project focused on developing guidance for the basic questions associated with where and how to introduce the feedback of realistic speeds and times (impedance) to trip distribution, mode choice, and assignment (feedback loops 1, 2, and 3 in Figure 3.2). Again, these are the feedback processes required by the 1990 CAAA and other federal regulations. The other feedback locations (transportation - land use interaction, time-of-day locations, composite impedances) are either the subject of additional ongoing research (transportation - land use interaction) or may be investigated in subsequent efforts.

---

1 The Figure 3.2 feedback location is shown in parentheses.

2 In a recent model development effort for the Volpe National Transportation Systems Center, JHK & Associates and COMSIS Corporation linked macro traffic simulation models (FREQ and TRANSYT) to a regional planning model to provide more accurate assessment of travel times and delays on the modeled links (JHK & Associates, 1994). The results of the macro simulation were then fed back to the planning model for a new iteration of assignment and the process repeated until convergence was achieved. A method similar to MSA was used to average the results from each iteration prior to feedback.

The remainder of this chapter provides guidance on how feedback should be implemented. The following four topics are addressed in the chapter:

- Basic concepts and definitions that are needed to understand the descriptions that follow
- A generic feedback framework
- Alternative feedback methods that can be used within the framework
- Desirable features and issues associated with implementing feedback

The feedback between assignment and trip distribution is used to illustrate the basic principles and methods for feedback. The same processes may also be extended to incorporate some of the other more complex interactions including the use of composite impedances and land-use interactions.

3.2 Basic Concepts and Definitions of Feedback

This section provides a brief discussion of some of the basic concepts and definitions that will be used throughout the rest of this handbook to explain and discuss feedback within the four-step travel forecasting process. These include:

- equilibrium
- iterations
- convergence, and
- what is meant by the "Sub-Problem Solution" and "Overall Solution" when feedback is discussed in the literature and in this guide.

3.2.1 Equilibrium

The concept of user equilibrium has been described and studied in traffic assignment for many years. It is a well-known attribute of traffic operations that an individual vehicle on a road causes delay (congestion) to other vehicles on the same road. As more vehicles use the same road segment some drivers may change their routes to avoid the delay (congestion) that they experience due to the other vehicles. This again may cause others on their new route to change their routes. **User Equilibrium** is reached when this "balancing" throughout the system results in conditions in which **an individual within the system cannot make an independent choice and improve their situation.**

In the 1950s, Wardrop provided the classical definition of user equilibrium for assignment, often referred to as Wardrop's First Principle:

- For each origin-destination pair, at user equilibrium, the travel times on all used routes are equal,
- and are (also) less than or equal to the travel time that would be experienced by a single vehicle on any unused route (Sheffi, 1985).

As people travel on different road segments, the travel time changes according to a volume-delay function. Travelers will change their routes until user equilibrium is reached.

The equilibrium concepts for assignment found in Wardrop's First Principle can be extended as other components of the four-step process are included. For example, including trip distribution allows the destinations one may choose for a trip to change based upon the travel times or levels of congestion to different locations. Equilibrium is reached when no individual can change their route, mode, or location independently and improve their overall situation. This is the definition that is used throughout this document when equilibrium is mentioned.

3.2.2 What is an iteration?

An **iteration** is simply the execution of a single pass of a feedback process. Often there are repetitions within a particular element of the travel forecasting process that are also referred to as iterations within those elements. Examples include repetitions found in trip distribution or capacity constrained assignment. This can lead to confusion and one must be careful to specify what iteration is taking place during discussions of a feedback process. Throughout this handbook, unless it is specifically stated otherwise, an "iteration" refers to an execution of a pass of the full feedback process.

3.2.3 Convergence

Convergence describes how stable a feedback process is at the end of any particular iteration. A process **converges** if it approaches a single value as the number of iterations increase. For a process to converge with respect to a particular measure, the average change for the measure between iterations must decrease and eventually approach zero as the number of iterations increases.

Convergence measures approach zero as equilibrium is reached and can be used to automate the determination of when to stop the feedback process. Examples of convergence measure include: 1) the percent change of a measure; 2) the Root Mean Square (RMS) change; and 3) the percent of values that have less than a 10 percent change. These and other convergence criteria will be described in more detail later in this chapter.

It is possible that two feedback methods will converge but at different rates. A second concept is therefore also useful to describe convergence characteristics. **Stability** is how the results vary from iteration to iteration. Again, criteria such as percent change, the RMS, or percentage of links with percent change less than 10 percent are measures of stability.

3.2.4 What are the "Sub-Problem" Solution and the "Overall" Solutions?

The literature on feedback processes and the combined models that incorporate feedback directly often refers to the "Sub-Problem" and "Overall" Solutions of a feedback process. As explained in Sections 3.3 and 3.4 all but one of the alternative methods for implementing feedback produce the final results of an iteration in two steps:

1. The individual elements of the process are executed for the iteration. For example, trip distribution, conversion to vehicle trips (mode choice), and assignment may be executed.

2. A new set of overall results are obtained by combining the iteration solution with the previous solutions.

The **Sub-Problem** represents the individual iteration of the feedback process. The results of each element in the feedback iteration form the sub-problem solution. The Overall Solution is the equilibrium for all of the elements within the feedback process. A new **Overall Solution** is obtained when the individual iteration's results are combined with previous values as the last step in the iteration. These concepts are best illustrated by describing the Generic Feedback Framework, which follows in the next section.

3.3 Description of General Feedback Framework

The need for incorporating feedback into the four-step travel forecasting process (or for developing combined models) has been identified for many years and a number of techniques have been explored to implement it (Sheffi 1985; Boyce 1994; Florian et al, 1975; Evans 1976; Horowitz 1991). In spite of the rich research and analysis on the subject, the implementation of feedback has continued to be rare in practice and its impacts are not well understood (U.S. EPA, 1993; Boyce, 1990). This has begun to change with the implementation of the ISTEA and 1990 CAAA.

One of the issues associated with the implementation of feedback is the perceived, and often real, difficulties associated with its implementation in current forecasting packages. Some of the difficulties encountered in the past include excessive computing time and storage and problems associated with automating the feedback of information in existing software packages. Consequently, an implementation of feedback should have the following features:

- It should be easily executed and understood in a production environment,
- It should be as efficient as possible to conserve computer time,

- It should conserve computer resources, especially storage requirements,
- It should include the capability to test for convergence or equilibrium conditions and an adjustable number of iterations to allow convergence to occur, and
- It should be compatible with existing travel forecasting processes.

As part of this project, a Generic Feedback Framework (illustrated in Figure 3.3) was identified to meet the above objectives. As shown in the figure any feedback process can be broken into a number of separate elements. These are:

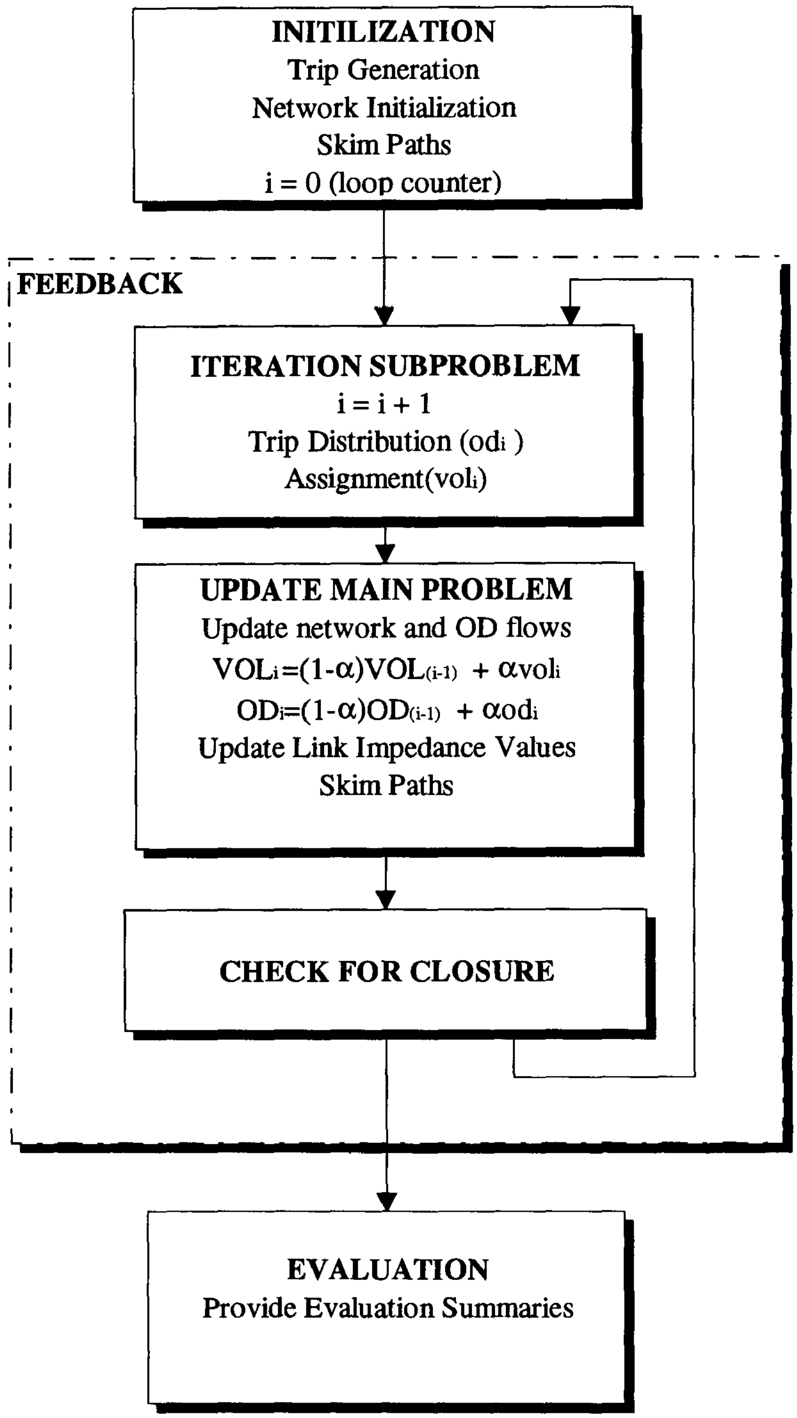
- **INITIALIZATION** - Initialization performs the steps of the feedback process prior to the beginning of the feedback iteration for the forecasting process being implemented. This includes the initialization (iteration 0) of the required skims, networks, and trip tables, to the starting conditions (typically free flow), as well as some book keeping to allow an iterative process to be established.

- **FEEDBACK: SOLVE SUB-PROBLEM** - The feedback portion of the general framework has three components of which the first is the execution of the four- step elements included in the feedback loop. As an example, trip distribution and assignment are shown in the Figure 3.3. Borrowing from optimization theory, the solutions from these runs are considered to be the "Sub Problem" solution (Boyce, 1995).

- **FEEDBACK: UPDATE OVERALL SOLUTION** - At the end of each iteration the overall solution is updated by combining the current overall solution (from the last iteration's update) with the sub-problem solution from the current iterates. There are a number of ways the updating can be performed including using the sub-problem's solutions directly (the direct approach), using fixed weights (the Method of Successive Averages), or weights based upon an optimal search (the Method of Optimal Weighting). The updating is performed using the same data sets for each iteration limiting the amount of disk storage space required to implement feedback. This step is important because the storage requirements can quickly become excessive if all datasets from all iterations are required for final adjustments.

  It should be noted that the travel times or impedances are not averaged. New times are developed by applying the volume-delay functions for each network link to the updated overall solution link volumes. The origin-destination flows (by mode) are also averaged to maintain consistency of the overall trip tables with the updated link volumes.

Figure 3.3: Generic Feedback Framework



odi, voli = Solutions to individual trip distribution, assignment, etc.from iteration i

OD_i, VOL_i = Updated Overall Solution from Averaging previous Overall Solution with Sub Problem

α = Weight to average solutions (will vary based upon feedback methods)

- **FEEDBACK: CHECK FOR CONVERGENCE.** Convergence occurs when the updated solution is both stable and close to equilibrium conditions. Various criteria include checking for maximum change in individual link volumes and origin-destination flows, the percent change in various average values such as speed, or calculating the change in different mathematical "objective functions." This is discussed more completely below. Because conditions such as congestion can cause the number of iterations required for convergence to vary, it is important that the number of iterations of feedback not be set at a low fixed value.

- **EVALUATION:** Evaluation completes the remaining steps after feedback and provides any summaries of performance measures produced as part of the process.

While the above iterative process may seem obvious, it is typically not how feedback has been applied in practice. In a brief search it was found that the typical implementation of feedback:

- Directly fed back the link travel times from assignment to distribution.
- Fixed a set number of feedback iterations in the base and future years.
- Hard coded the process making the number of iterations and convergence analysis difficult to check and modify.

As illustrated in Figure 3.3, the overall solution of the feedback process is updated at the end of each iteration, and new inputs for the next iteration are prepared. There are a number of alternative methods to perform this updating of the overall solution, and these are examined in the section that follows.

3.4 Alternative Methods for Implementing Feedback

A number of different methods have been identified for implementing feedback iterations within the Generic Feedback Framework. They include:

1. **Direct Method.** The first method can be considered the naive approach to feedback because it is the most obvious and probably the easiest feedback approach to implement. It executes the four-step process and then uses the final assigned volumes to calculate new speeds and travel times for input into the next iteration's trip distribution. In the Direct Method, results from previous iterations are not combined with the current iteration to obtain a new overall solution. The steps for a trip distribution to assignment feedback process using the direct method are:

1. Trip Generation
2. Update speeds and origin destination travel times based upon assigned volumes (for first execution assume free flow speeds)
3. Trip Distribution
4. Conversion of person trips to vehicle trips (mode choice and vehicle occupancy)
5. Capacity constrained assignment
6. Check for Convergence (if yes go to step 7, if no return to step 2).
7. Evaluation

This approach has been shown by Florian (1975) not to converge in all situations, and has the potential to oscillate. One example, illustrated in Figure 3.4, is provided by a research effort undertaken internally by the Federal Highway Administration. Using data from Baltimore, Maryland and Nashville, Tennessee, the researchers found that there was instability in the approach from iteration to iteration and no sign of convergence to a consistent set of values. In many cases, convergence will occur using the Direct Method but often only after many iterations and the consumption of considerable clock time and computer time.

A number of alternatives to the Direct Method have been identified by previous researchers and practitioners as ways to speed processing time and assure convergence. All of the alternatives represent methods for using information from previous iterations to direct the new iteration forecasts toward a convergent solution. The methods use somewhat different approaches either in the assignment algorithm or in the method for combining results of previous iterations to produce new input values.

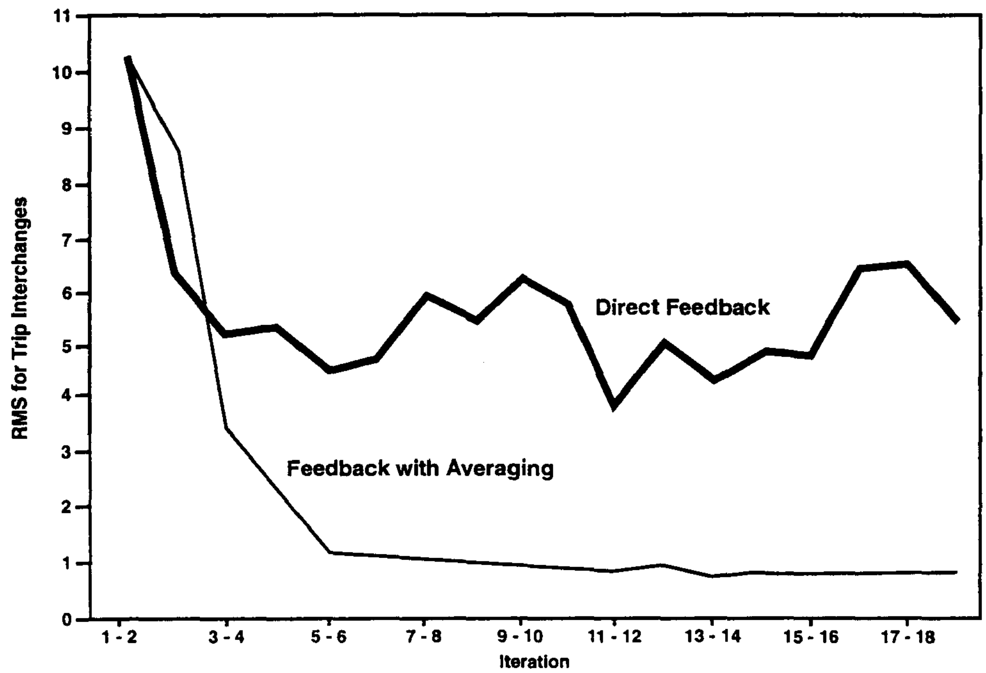
2. **Method of Successive Averages With All-Or-Nothing Assignment (MSA-AON).** This method is a heuristic alternative to the models that mathematically combine the distribution-assignment and other feedback iterations directly (Sheffi 1985, Horowitz, 1991; Boyce 1994). It combines results from previous iterations and the current iteration to produce updated volumes and trip tables. It averages each new iteration's results with the previous results using a weight of 1/N (where N is the iteration number). This is equivalent to a simple average where all iterations have equal weights. This method has been shown to always converge. Its steps are:

1. Trip Generation
2. Update speeds and origin destination travel times based upon averaged volumes (for first execution assume free flow speeds)
3. Trip Distribution
4. Conversion of person trips to vehicle trips (mode choice and vehicle occupancy)

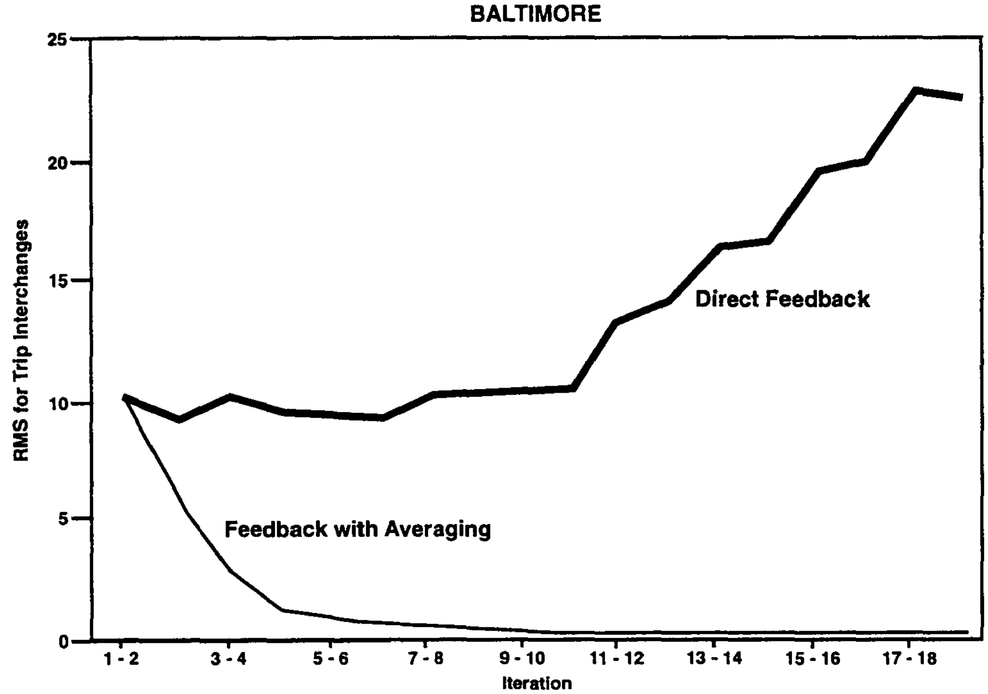
Figure 3.4: Comparison of Direct Feedback and Method of Successive Averages

Root Mean Square for Trip Interchanges

NASHVILLE



BALTIMORE



Source: FHWA, 1994

5. All-Or-Nothing Assignment

6. Average volumes on each link and each origin destination flow with previous results as follows:

$$Value_n = (Iteration\ Value)_n * (1/n) + Value_{n-1} * ((n-1)/n)$$

Where:

n = number of current iteration

Value = Values to be averaged: link volume and origin destination flows

Iteration Value = Results from the current iteration.

7. Check for convergence (if yes go to step 8, if no return to step 2)

8. Evaluation

3. **Method of Successive Averages With Equilibrium Assignment (MSA-EQA).** This approach is similar to the previous MSA approach except that a full equilibrium assignment is performed as part of Step 5. It has been observed that in applications of the MSA-AON approach, the variation due to the assignments typically is much greater than the variation due to the trip distributions (Horowitz, 1991). Using a full equilibrium assignment may, therefore, result in more rapid convergence between iterations of feedback.

4. **Method of Optimal Weighing with All-Or-Nothing Assignment (MOW-AON).** One approach for overcoming the issues associated with direct feedback is to directly connect the different elements of the process together using mathematical procedures shown to converge. Suzanne P. Evans first proposed a procedure for combining trip distribution and assignment in 1976 which is commonly called the Evans Algorithm (Evans 1976). Others have extended or modified her initial efforts and extensive research has been performed on these "combined models" (Horowitz, 1991; Florian et. al, 1975; Boyce et. al., 1994; Boyce et. al., 1988; Walker and Peng, 1995; Sheffi, 1985; Ortuzar and Willumsen 1990), but only recently has their use for production applications begun to be considered practical.

   These "combined" approaches are all in essence successive averaging procedures similar to the Methods of Successive Averages (MSA) described above. Instead of using a weight of 1/N to average the link volumes and origin-destination flows, however, these procedures use a mathematical program similar to that used in equilibrium assignment to find the "optimal" weight for each iteration.

The steps in a Method of Optimal Weighing with All-Or-Nothing Assignment are:

1. Trip Generation
2. Update speeds and origin destination travel times based upon averaged volumes (for first execution assume free flow speeds)
3. Trip Distribution
4. Conversion of person trips to vehicle trips (mode choice and vehicle occupancy)
5. All-Or-Nothing assignment
6. Determine optimal combination (weights) of this iteration's volumes and origin destination flows with previous results
7. Average volumes on each link and each origin-destination flow using the weights determined in Step 6
8. Check for convergence (if yes go to step 9, if no return to step 2)
9. Evaluation

The Method of Optimal Weighing is more complex to implement and may require special programming or capabilities not normally found in travel forecasting packages in current use in the United States. Each of the different MOW formulations may also require specific assumptions or attributes for the individual elements of the forecasting process. For example, the Evans Algorithm's basic assumptions include:

- Trips are assigned to the transportation networks in such a way that Wardrop's First Principle (no individual can improve their condition by independently changing their route) applies.

- The cost of traveling along each link of the network is represented by a known strictly increasing function of the traffic flow on the link. This function, or volume-delay function, also increases indefinitely as the capacity of the link is reached.

- The trip productions and attractions for each zone for the time period being analyzed are fixed.

- The trip distribution deterrence function representing the perceived separation between zones is represented by an exponential function of the form:

$F_{exponential} = \alpha A_i B_j \ e^{-\beta t_{ij}}$

Where:

α, β *= calibrated constants*

t_{ij} *= travel time or impedance between origin i and destination i*

A_i, B_j *factors related to the productions and i and the attractions at j*

- Trip distribution is represented by a doubly constrained gravity model using the above exponential deterrence function. A doubly constrained gravity model adjusts the trips between origins and destinations such that both the target productions and attractions are matched for each zone. A separate formulation was also provided by Evans for a singly constrained gravity model which guarantees the preservation of only the productions in each zone.

  Because of the complex nature of these methods and the potential for mis-specification, it is recommended that they only be implemented with the assistance of someone well versed in mathematical programming and the theory of the combined models.

5. **Method of Optimal Weighing with Equilibrium Assignment (MOW-EQA).** Again, most of the variation between iterations in the above method is due to the AON assignment and not trip distribution. Thus, an equilibrium assignment can also be performed as part of Step 5 to reduce the number of iterations of feedback.

3.5 Desirable Features and Attributes Associated with Implementing Feedback

There are a number of additional features that should be included in any implementation of a feedback process. These include:

- The process should be easily executed and understood in a production environment.
- It should be a self-repeating "iterative" process.
- The number of iterations should be variable and determined by convergence criteria.
- The convergence criteria should be easily understood and capture both the stability of key measures and the proximity of the final solution to equilibrium.
- It should use real arithmetic or "bucket rounding" to control for accumulated round-off error in matrix calculations if integer arithmetic is used.

This section more fully examines some of these desirable features and attributes of a feedback process and how they are implemented within the Generic Feedback Framework.

3.5.1 The Process should be easily executed and understood in a production environment

With any implementation of feedback within the four-step process the potential for errors and mis-specification increases dramatically. For example, a simple mis-specification of using the congested time from the previous iteration as the initial time for the volume-delay functions that calculate link speeds can cause the speeds to always deteriorate from iteration to iteration regardless of the volume on the link. Also, if the production process depends upon complicated setups and procedures that must be updated manually for every run, the likelihood that mistakes will be made by staff during forecasting is increased. Finally, the more feedback mechanisms that are included in a process, the more difficult it is to understand and explain the results to those using the forecasts to make policy decisions. A recent paper (Levinson and Kumar, 1993) described an implementation of feedback that included direct feedback for:

- Time of departure
- Traffic operations
- Mode choice
- Trip distribution
- Assignment

The number of interactions that this application takes into account is impressive, but it creates a set of very complex relationships to explain. For example, the paper notes the sensitivity of transportation demand and traffic patterns to intersection controls. Because impacts of each feedback cascade through the system, the forecasting application also has the potential to produce regional changes in travel patterns based upon very localized network improvements. With this number of interactions it is important that the impacts of improvements to the transportation system be fully explored and understood by those producing the forecasts. It is recommended that feedback mechanisms be implemented in a prudent fashion, and with the simplest procedures required to capture the desired interaction.

3.5.2 Need for an Automated Iterative Process

One of the key recommendations of this research is that the feedback processes be developed in an automated, iterative (instead of sequential) manner and it should not require the retention of every iteration's results to execute and obtain the final solutions. This is recommended for three main reasons:

- The implementation of feedback is complicated, and repeating drivers/setups in a sequential fashion to execute each iteration is prone to error and difficult to maintain. Desired changes to the process must be repeated in the setups for each iteration. Dataset names must also be changed in multiple locations for each new alternative or scenario being forecasted. In past studies this has proven to lead to mistakes and hidden errors in the forecast results.
- Using a non-iterative process can lead to excessive data storage.
- A sequential setup makes it difficult to implement processes that allow the number of iterations to vary based upon closure criteria.

This process can be implemented by maintaining two sets of data: one for the overall solution and one for the results from the current iteration. A process for updating the datasets of the sub-problem solution is illustrated in Figure 3.5. As shown, some forecasting software may require additional temporary datasets for updating the overall solution. Examples of the setups for the Memphis and Salt Lake City test cases (described in Chapter 4) have also been developed and were provided as part of the **Interim Report for Task 2.D: Initial Feedback Test Cases**. additional temporary datasets for updating the overall solution. Examples of the sets for the

3.5.3 Variable Number Of Iterations with Convergence Criteria Determining Termination

Another important element of the feedback implementation is establishing a process in which the number of iterations depends upon a set of convergence criteria designed to check both stability and proximity. Figure 3.6 shows the impact of congestion on the number of iterations required for

Figure 3.5: Iterative Process for Data Storage Within the Generic Feedback Framework

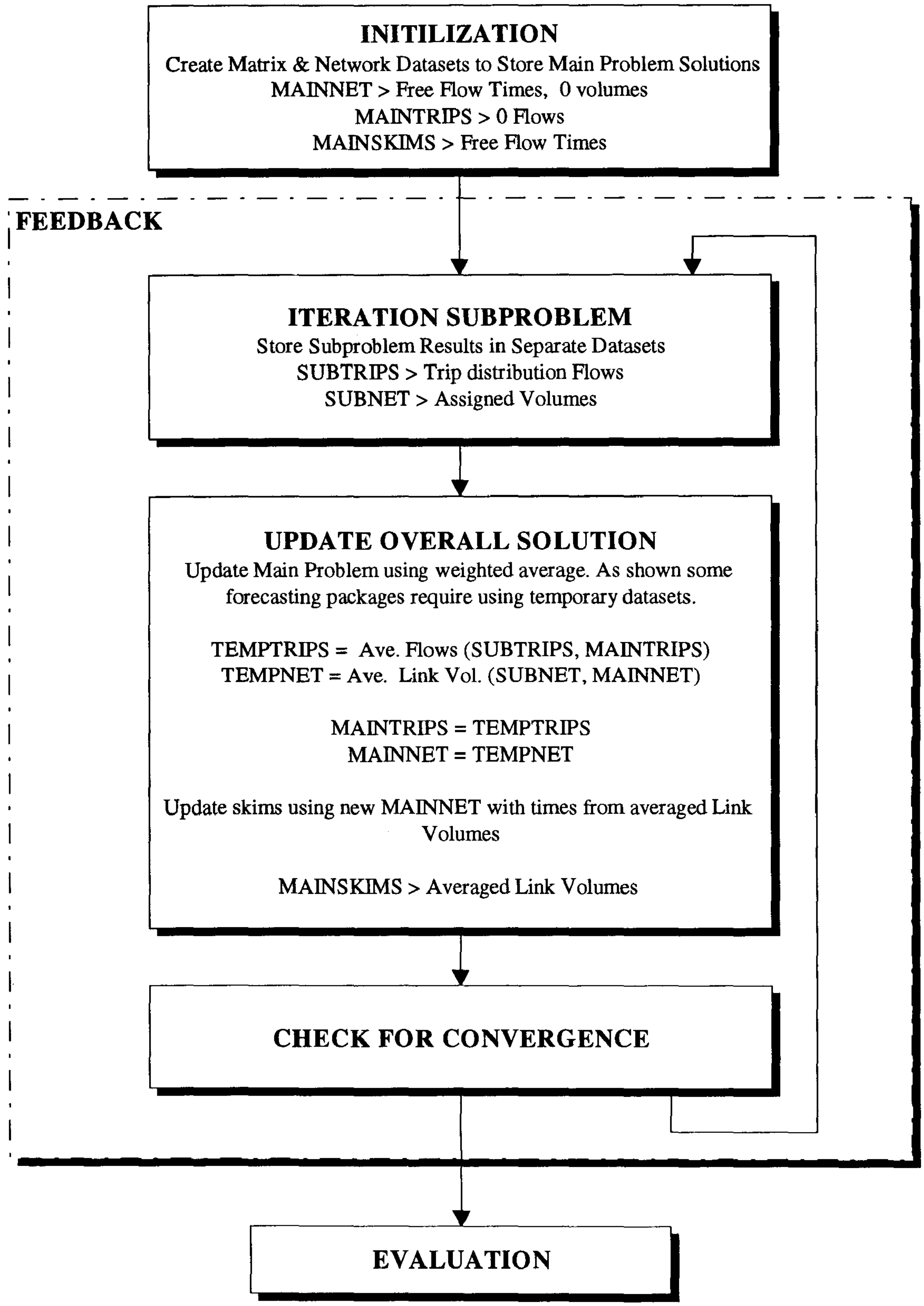
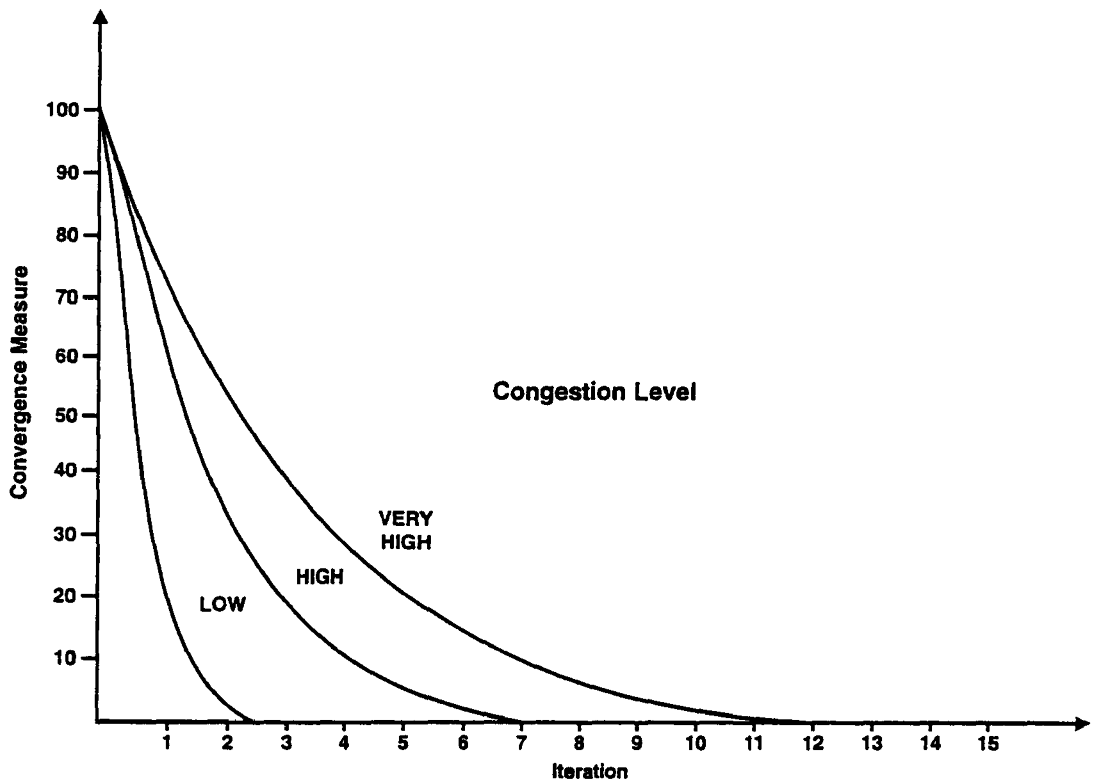


Figure 3.6: Impact of Congestion on Number of Iterations Required for Convergence



Source: Sheffi, 1985

convergence in equilibrium assignment (Sheffi, 1985). The figure indicates that as congestion increases from low to very high levels, the number of iterations required to reach equilibrium increases from two to more than ten. Walker and Peng report the need for fifteen iterations within equilibrium assignment to reach closure in the future networks for Philadelphia (Walker and Peng, 1995).

The impacts of congestion on feedback were also found in the results of the test cases for Memphis and Salt Lake City as described in Chapter 4. These cases showed, however, that the impacts seem to be more significant at a localized level than at the regional level. Consequently, tests for convergence should also be performed for geographic subareas of concern and not simply for the modeled system as a whole.

The Generic Feedback Framework includes checking for convergence as the final step of an iteration of the feedback process. How this is performed depends upon the specific application and software used. MINUTP, EMME/2 and possibly other travel forecasting packages now have the capability to calculate internal statistics and alter the flow of execution based upon the results. If a process is batch-oriented, then programs can also be written to update the MS-DOS ERROR LEVEL variable and use the MS-DOS batch commands to adjust the flow of execution. The software vendors, or other consultants, should be contacted to determine the best way to implement the checking for convergence in a specific forecasting environment.

3.5.4 Convergence Criteria

A number of convergence criteria were investigated for this effort. A full list of the proposed criteria are described in the Interim Report for Task 2.B: **Definition of Closure and Feedback Evaluation Criteria** and the **Interim Report for Task 2D: Initial Test Cases**. This section focuses on the set of recommended criteria that proved to be useful during the evaluation of the test cases. As already discussed, there are two attributes of the solutions that should be examined: convergence to true equilibrium conditions and stability between iterations.

From the research conducted in this study, it was found that many of the identified convergence criteria produce similar results. Some of the measures proved to be insensitive to changes caused by feedback and so a smaller set of key measures can be used to track the feedback application's performance. The specific measures used need to capture the change in the link volumes and origin-destination flows as well as changes in key output variables such as speed. It was found that the average system variables did tend to be more stable than individual link or origin destination values. The recommended measures are:

1. **Percent Change in average speed by functional class and area type -** This measure, though relatively unstable, captures the main criteria for introducing feedback for conformity analysis of providing consistent speeds throughout the process. It should therefore become part of each iteration's outputs.

2. **Percent of links with less than 5 percent change in assigned volume -** Measures the stability of the assignment and wide variations in link flow.

3. **Root Mean Square (RMS) of assigned link volume -** This measure provides another way of estimating the stability of the assignment but places more significance or weight on large errors.

4. **Percent of person trips with less than 10 percent change in origin-destination flows -** This measure captures the stability of the distribution and the number of origin-destination interchange between which large changes may be occurring. It is weighted by the origin-destination flows of the previous overall solution to minimize the impact of small interchanges shifting one to two trips yet with a large percentage change. (A change from 1 to 2 is a 100 percent change)

5. **RMS of origin-destination flows -** This measure provides another way of estimating the stability of the trip distribution that again places more significance on the large changes between iterations.

Again, it may be important to estimate these values at both the regional level and for specific subareas. The acceptable limits for each can then be built into the iterative process for automated testing of convergence. These limits should be set during the model validation phase based upon what is shown to be an acceptable value for the area under study and the policy issues to be examined.

For feedback mechanisms with mathematically formulated objective functions, true measures of convergence can be defined. These include both equilibrium assignment and the combined distribution and assignment. The "gap" is a measure of how close the solution is to the true equilibrium condition at any iteration. The objective function and Gap for the equilibrium traffic assignment problem are described in more detail in Florian (1991).

3.5.5 Use of Real Arithmetic or "Bucket Rounding" to Control Accumulation of Matrix Calculations

In the Generic Feedback Framework, each iteration's results are combined with the previous iterations to produce a new overall solution. Because of the iterative nature of the process, this results in the averaging of the current iteration results with the previous overall solution which was the average of its results with its previous overall solution. This averaging of averaged results creates the potential for accumulation of round-off error, especially in matrix calculations, if calculations are performed in integer arithmetic.

As the iterations increase, the sum of individual results can exceed the maximum units for a matrix cell value of most software packages. The recommended solutions to this problem are:

- Maintain the trip tables during the feedback process as real values - Many travel forecasting packages are now providing the capability to store trip tables, or other matrices as real numbers or decimals. If this option is available it should be used. The advantages of this option are increased precision in reaching equilibrium during processes that seek an optimal solution (Evans Algorithm) and reduced round-off in the averaging process. The disadvantages are that it may lead to larger file sizes and single precision real values have only seven significant digits. Unless double precision values are used when large interchange values occur, round-off error may also occur.

- Bucket rounding during the feedback process - Another option is to use bucket rounding during the averaging processes preserving either the row or column totals of each trip table. Bucket rounding is a technique that keeps each fractional element and adds it back in when accumulated to a whole number, in order to preserve a total value. This option was used in the final procedures developed as part of the test cases in this project. The following steps should be executed to bucket round:

(1) Multiply trip tables by a constant (10, 100, 1000...);

(2) Average; and

(3) Divide new table by the same constant and use a bucket round option to preserve the row or column total.

4. THE EFFECTS OF FEEDBACK

4.1 Selection of Regional Models for Testing

To test the applicability, operational characteristics and effects of feedback in the traditional four-step process and to provide an assessment of alternative methods for implementing feedback, a case-study approach was used. Model systems for two major metropolitan areas; Memphis, Tennessee and Salt Lake City, Utah; were selected for the case-study applications. The two sites provided a variety of land-use, network, and level-of-service characteristics and also represented two metropolitan areas for which the research team already had a significant amount of model data available. Both model systems forecast daily travel and use peak-hour factors to represent the relationship between volume, capacity and speed.

This section of the handbook provides a description of the convergence characteristics, execution time requirements and the effects on travel characteristics of each of the five main methods for implementing feedback when applied in the two test case models. The five methods evaluated were as follows:

- Direct Method
- Method of Successive Averages with All-or-Nothing Assignment (MSA-AON)
- Method of Successive Averages with Equilibrium Assignment (MSA-EQA)
- Method of Optimal Weighting with All-or-Nothing Assignment (MOW-AON)
- Method of Optimal Weighting with Equilibrium Assignment (MOW-EQA)

The results of introducing feedback into the modeling process are generally reported for feedback from assignment to trip distribution but without full integration of mode choice into the feedback process (a constant set of factors is used to convert the person trip tables produced by trip distribution to vehicle trips for assignment). This chapter does include a discussion of the effect of introducing mode choice into the feedback process. The results reported for mode choice are for the Salt Lake City model which had the most significant variation in congestion in the network and the most complex mode choice process of the two test-case model systems.

Because the goal of the project was to give practitioners guidelines on when and where to apply feedback, the models were selected to encompass attributes that may be affected by applying feedback. Some of the attributes considered in the selection of the test-case models are as follows:

- level of detail (number of zones) in the model,
- number and type of modes,
- explicit time-of-day procedures and data for speed and time by facility type and time period,
- availability of functional class and other attributes for the network links,
- variation among selected modes, and
- recent validation datasets including networks, demographic data and models.

Eleven candidate model systems were considered before the Memphis and Salt Lake City models were selected.

The model system for the Memphis metropolitan area is maintained by the Memphis Metropolitan Planning Organization and has been validated for a 1988 base year. A regional population of slightly less than one million is represented in 365 zones. The highway network for the model has all major roads coded and the transit system has three types of modes: regular/local bus, blazers or express bus, and north/south or cross-town routes. The trip purposes of the model are home-based-work, home-based-other, non-home-based, trucks and taxis, and external trips. A gravity model is used for trip distribution and a multinomial logit model is used in the mode choice procedure.

The model for the Salt Lake City metropolitan area uses 556 zones to represent the regional land use which also supports a population of about one million. A base year of 1990 has been established and a validation has been performed for that year. The highway network also has most of the major roadways coded and includes local and premium bus services in the transit network. Trip purposes modeled include home-based-work, home-based-other, non-home-based, home-based-college, commercial, and external trips. A gravity model is the basis for trip distribution, and a nested-logit model has been developed for the mode choice process to model five modes: drive alone, two-person carpool, three-plus-person carpool, local bus, and premium bus.

The two case-study sites provided reasonable variation because the baseline conditions for Salt Lake City included considerable congestion while the Memphis base-year model had only a small amount of congestion in selected locations. The system-wide average V/C ratio for Salt Lake City is 0.98 whereas for Memphis it is only 0.50. The discernable difference between the two case sites provided sufficient opportunity to use sensitivity testing with the two models to produce a wide variety of conditions. Sensitivity tests were conducted by testing the effects of twenty-five percent uniform growth throughout the area, twenty-five percent radial growth along selected growth corridors and the effects of a major new facility being added into the highway network.

4.2 Operational Characteristics of Feedback

4.2.1 Convergence Characteristics

The convergence criteria and measures for evaluating feedback described in Chapter 3 were produced for each of the initial feedback processes. The measures included values to test for convergence (internal) and to test the impact of the feedback on travel forecasting process outputs (external). Different criteria were defined to examine the univariate impacts of feedback, the frequency distributions of those impacts, and their geographic patterns. A comparison of the convergence characteristics of the alternative feedback methods when implemented in the Memphis model suggested very little difference between the methods. This was not the case for the Salt Lake City model where significant differences in convergence speed and stability were evident. The difference in results for the two model system illustrates the relationship between network congestion and the role and effect of feedback. Because feedback would generally be implemented (or make a difference) only when congestion exists in a network, the convergence performance results for Salt Lake City are used here to illustrate the relative performance characteristics of the five alternative methods for implementing feedback. Sample results for Salt Lake City are presented in Figures 4.1 - 4.3.

The test case results for Salt Lake City demonstrate the value of using one of the averaging methods over the direct feedback method (Direct Method). The averaging methods with an equilibrium assignment each produced faster and more complete convergence than the Direct Method with Equilibrium Assignment.

Figure 4.1: Comparison of Convergence Characteristics for Alternative Feedback Methods: Percent of Links with <10% Change in Volume Salt Lake City Model

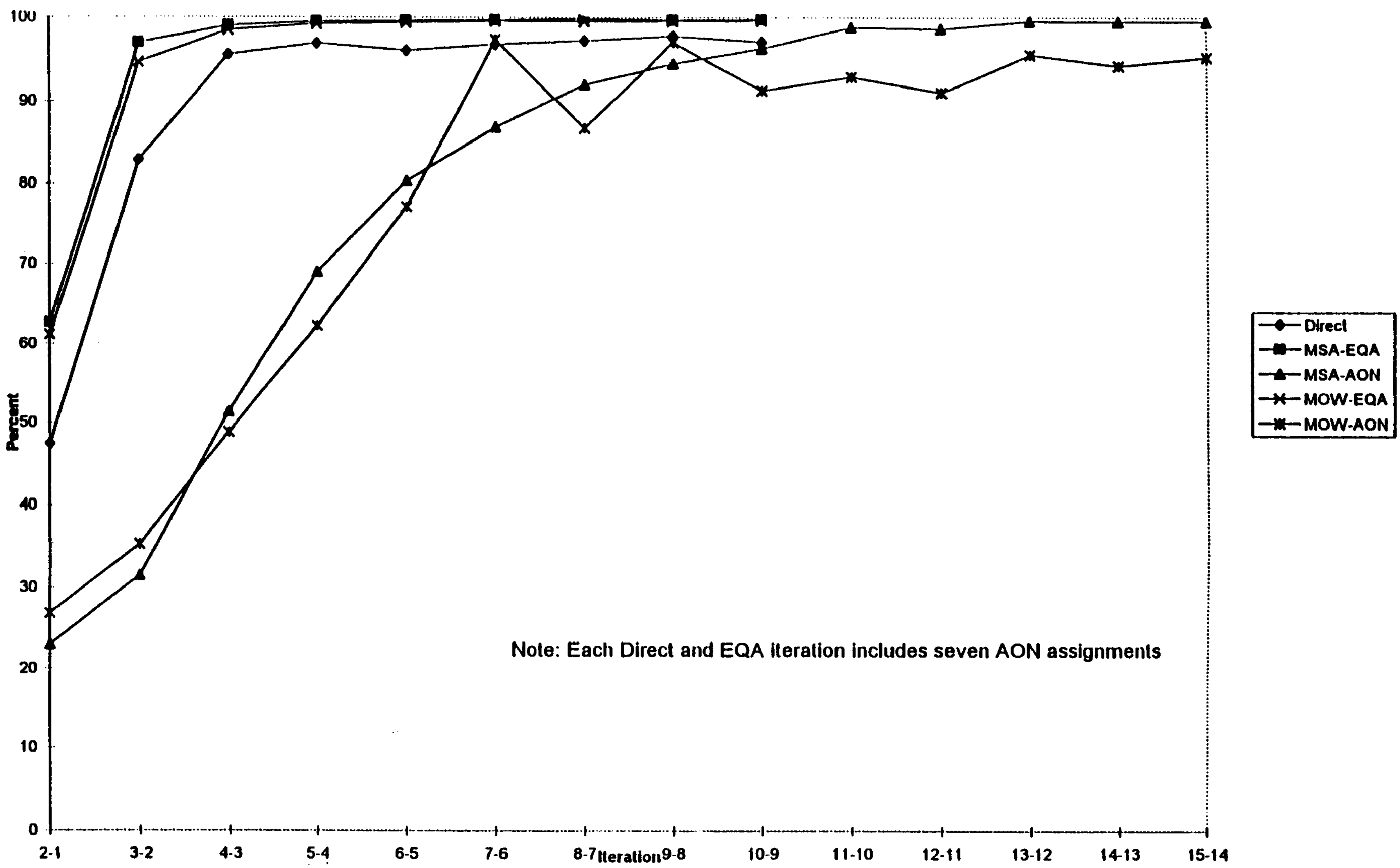


Figure 4.2: Comparison of Convergence Characteristics for Alternative Feedback Methods: Percent Change in Average Speed Salt Lake City Model

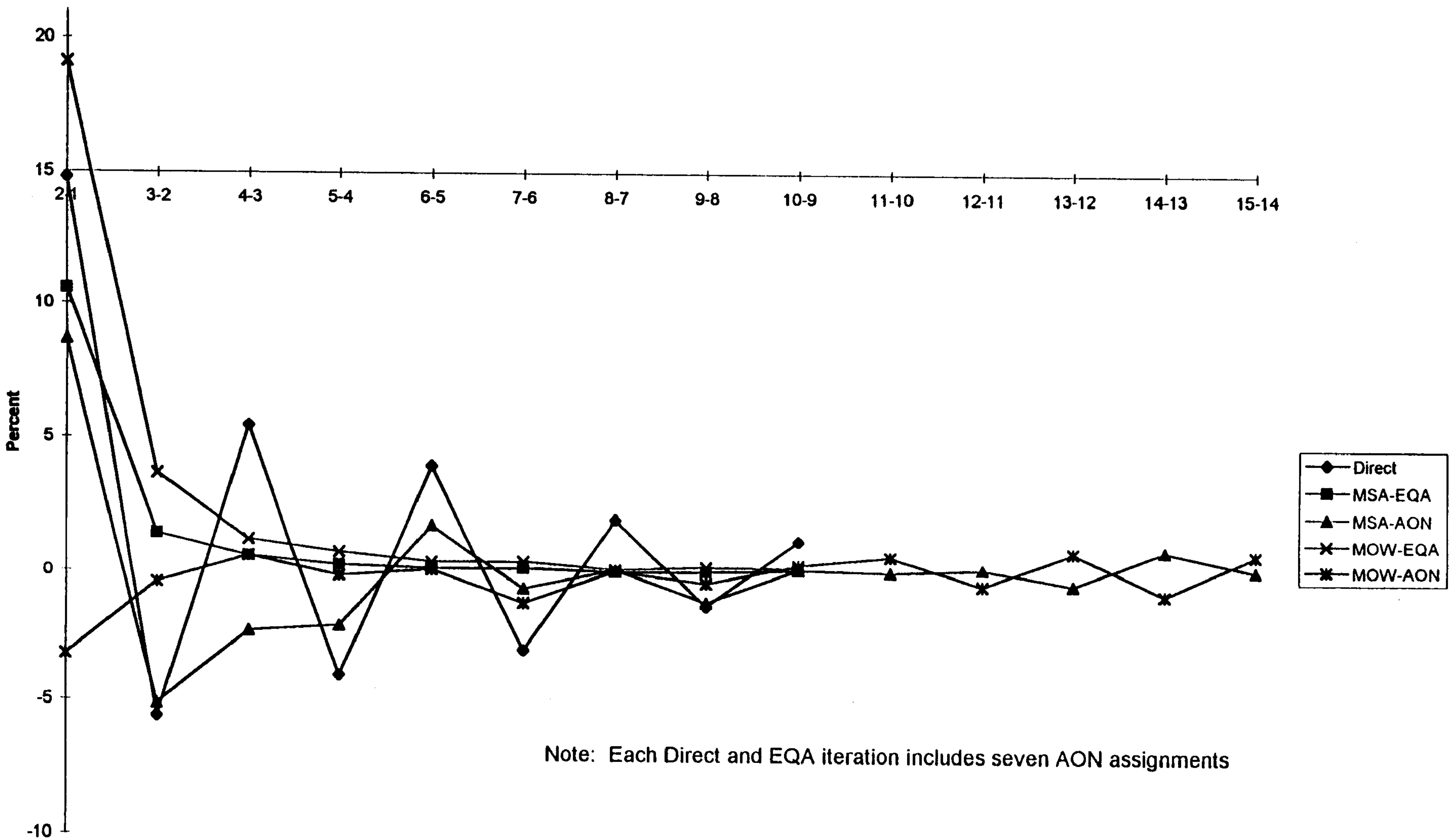
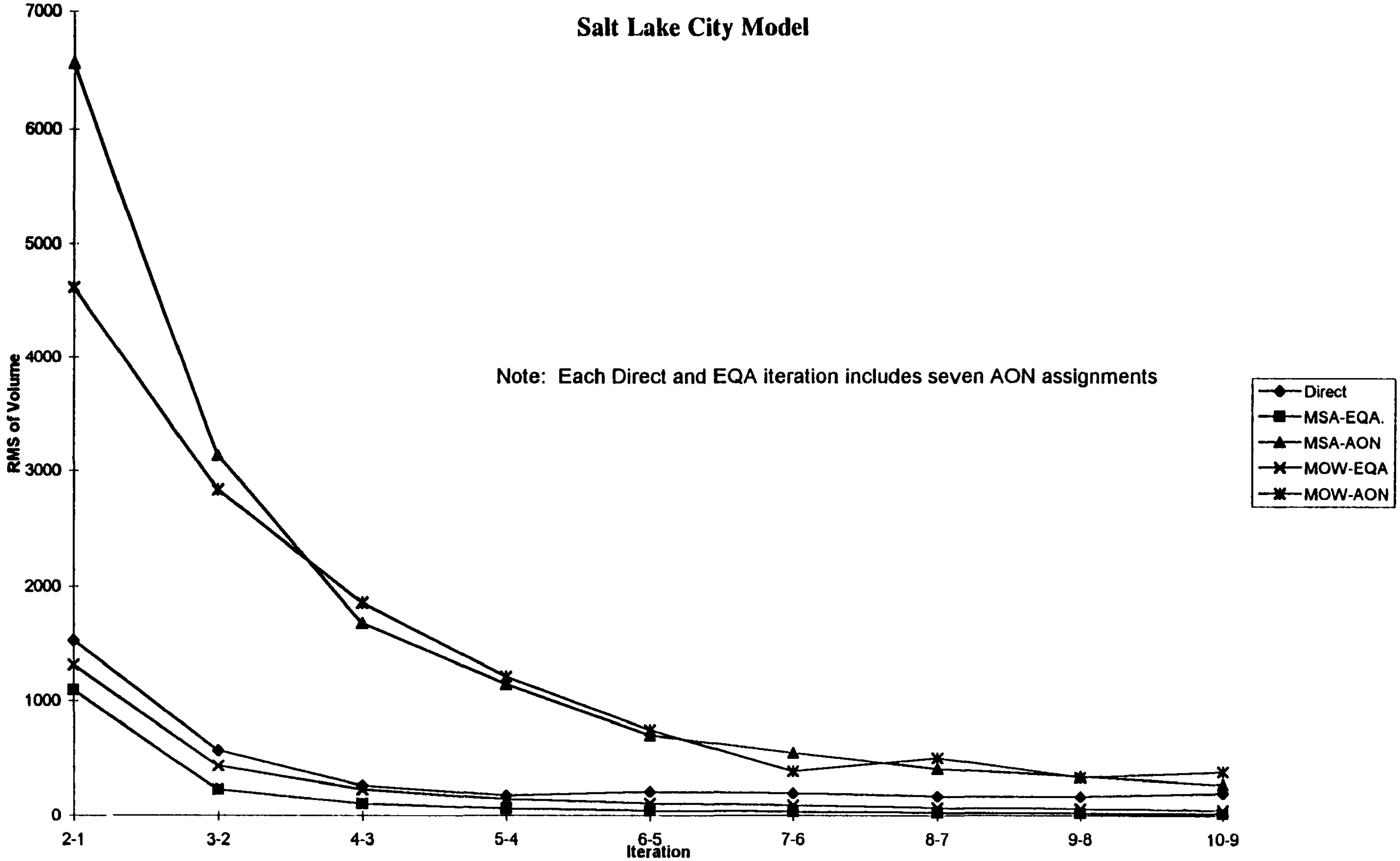


Figure 4.3: Comparison of Convergence Characteristics for Alternative Feedback Methods: RMS of Volume Salt Lake City Model



The methods using all-or-nothing assignments (MSA-AON and MOW-AON) took many more iterations to stabilize and converge. It should be noted, however, that each iteration of one of the methods using equilibrium assignment have seven iterations (four for Memphis) of all-or-nothing assignment within the assignment step alone. Much of the superiority in convergence speed of the MSA-EQA and MOW-EQA can be attributed to the additional iterations of all-or-nothing assignment within the equilibrium assignment.

When tested in the Salt Lake City model, the Method of Optimal Weighting demonstrated convergence characteristics almost identical to the Method of Successive Averages: MOW-EQA demonstrated convergence characteristics similar to MSA-EQA and the performance of MOW-AON was similar to that of MSA-AON. Similar results were obtain using a comparison of percent change in volume and speed. The applications in the Salt Lake City model system showed no significant improvement in convergence characteristics with MOW and the execution time was considerably greater than MSA. While the results for Salt Lake City do not indicate that the additional complexity of the MOW produces better or faster convergence, other researchers have suggested that for large networks with extreme congestion, MOW-AON may produce more efficient convergence than either of the MSA options (Walker and Peng 1995).

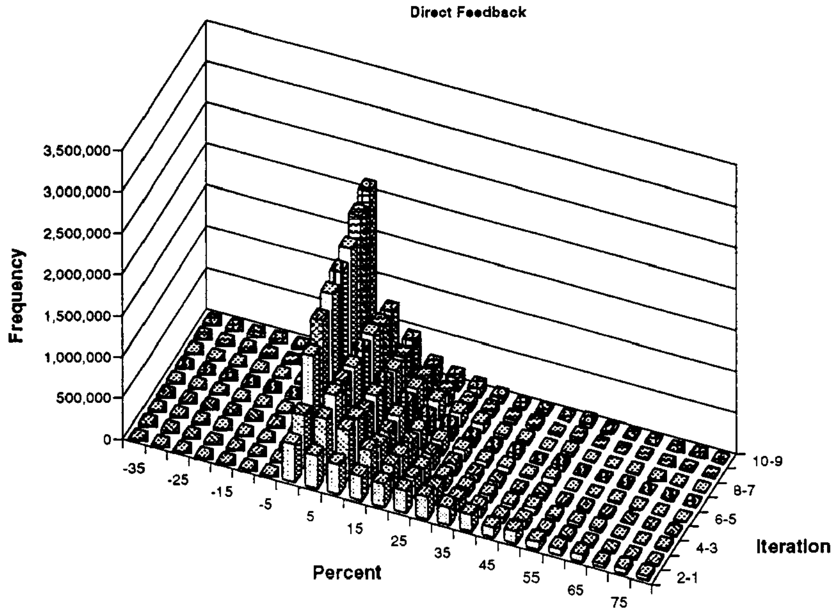
Table 4.1 provides a comparison of the execution times for three of the feedback methods (Direct, MSA-AON and MSA-EQA) and for the no-feedback baseline. For the test cases, feedback resulted in execution times roughly five to eight times that of no feedback for the Memphis model and 1.5 to 1.9 times that of no feedback for the Salt Lake City model. Of the three feedback methods tested, the one method using all-or-nothing assignment had a noticeably shorter execution time but also took considerably more iterations to converge. It should be noted that the different applications did not terminate in relation to a specific convergence criterion but were instead set to run for a fixed number of iterations (10). The superior convergence characteristics of the MSA-EQA over the Direct Method are further illustrated by Figure 4.4. In these graphs, convergence of feedback between assignment and trip distribution is reflected by the percentage of trips that shift origin-destination cell in a trip distribution matrix between iterations. The figure illustrates that after ten iterations, roughly two million trips in the Salt Lake City trip table had no change in origin-destination distribution using the Direct Method. However, using MSA-EQA roughly three million trips had no change after the third iterations and virtually all change was eliminated in origin-destination distribution after the fourth iteration.

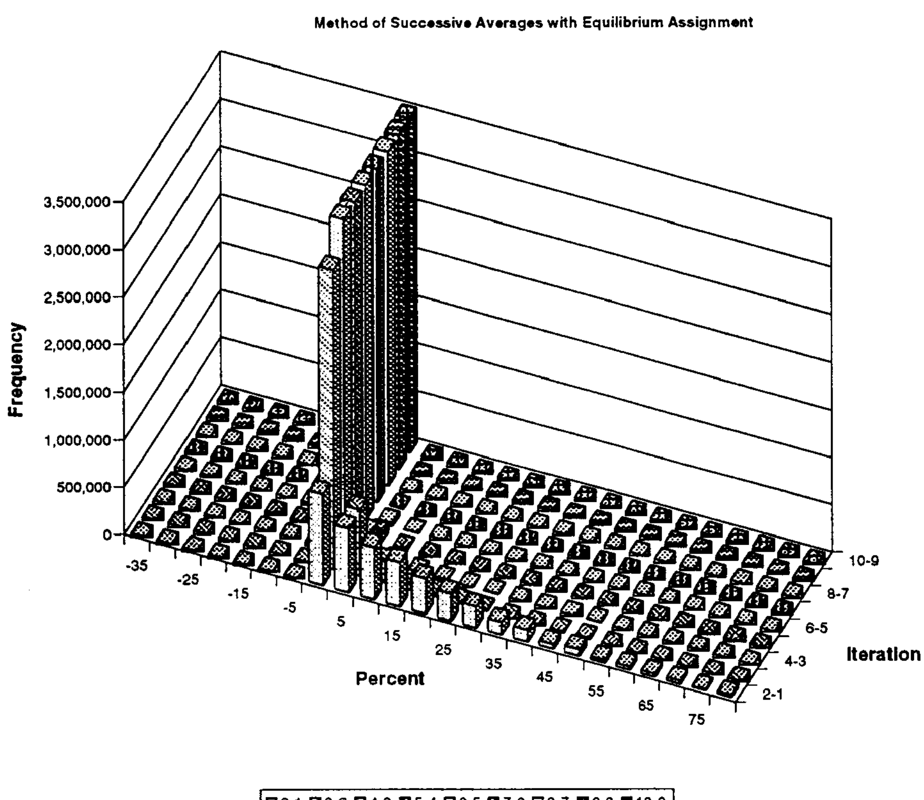
Table 4.1: Effects of Feedback on Model Systemwide Execution Time

Feedback		Execution Time (in minutes)					
Method	Number of Iterations	Distribution	Transit	Mode Choice	Assignment	Updates	Total
Memphis							
No Feedback	1	1.3	2.2	0.7	2.3	0.0	6.4
Direct	10	12.8	3.4	0.7	22.8	4.7	44.4
MSA-EQA	10	12.3	3.4	0.7	22.3	13.7	52.4
MSA-AON	10	11.3	3.4	0.7	4.9	12.2	32.4
Salt Lake							
No Feedback	1	2.3	58.0	42.4	5.5	0.0	108.2
Direct	10	23.0	58.0	42.4	55.0	16.5	194.9
MSA-EQA	10	21.0	58.0	42.4	50.7	34.0	206.1
MSA-AON	10	22.3	58.0	42.4	7.3	35.2	165.2

MSA - Method of Successive Averages

Figure 4.4: Comparison of Convergence in the Frequency of Person Trips by Percent Change in Person Trips for the Salt Lake City Model





4.2.2 Execution Time

Figures 4.5 through 4.8 provide a comparison of the MOW methods with the other methods. The figures illustrate graphically that while the MOW methods produce no significant improvement in performance characteristics in the test-case models, the execution time for MOW was considerably longer than for the other methods. The execution time of MOW may be reduced by using approximation methods, but is longer than the simpler MSA method by definition.

4.3 Effects on System-wide Travel

The effects of feedback on system-wide travel characteristics was tested by comparing the results of test-case model applications without feedback to results with feedback but without complete recalibration adjustments (some limited recalibration of trip distribution function factors match the original trip length frequency distribution was performed). The comparisons were made using the baseline model applications from Memphis and Salt Lake City, and using three sensitivity tests in which the models inputs were artificially manipulated to reflect significantly different travel characteristics.

(1) Uniform 25 percent growth for all productions and attractions in the region. This tests the increase in congestion on the system. Since Memphis and Salt Lake had very different initial congestion levels it also provided a range of conditions for the study.

(2) 25 percent total regional growth in productions and attractions distributed radially. This sensitivity analyses explores if there is a difference in feedback's influence depending on the patterns of congestion. The same total regional growth as found in the Uniform Growth case was used. In this case the percent growth of a zone is a function of its distance from the CBD. The zone at the center of the CBD receives zero growth.

(3) Addition Of A New Facility. New facilities and connectivity can also cause major shifts in travel patterns and origin-destination travel times throughout a region. In Memphis a circumferential freeway, or "Beltway" was added to the network outside the current beltway. This is shown in Figure 4.9. In Salt Lake a new radial facility was added in the vicinity of heavy congestion shown in the base runs. The Salt Lake City facility is shown in Figure 4.10.

Figure 4.5: Comparison of Execution Times for Alternative Feedback Methods: Average Execution Time of Steps Within One Feedback Iteration Salt Lake City Model

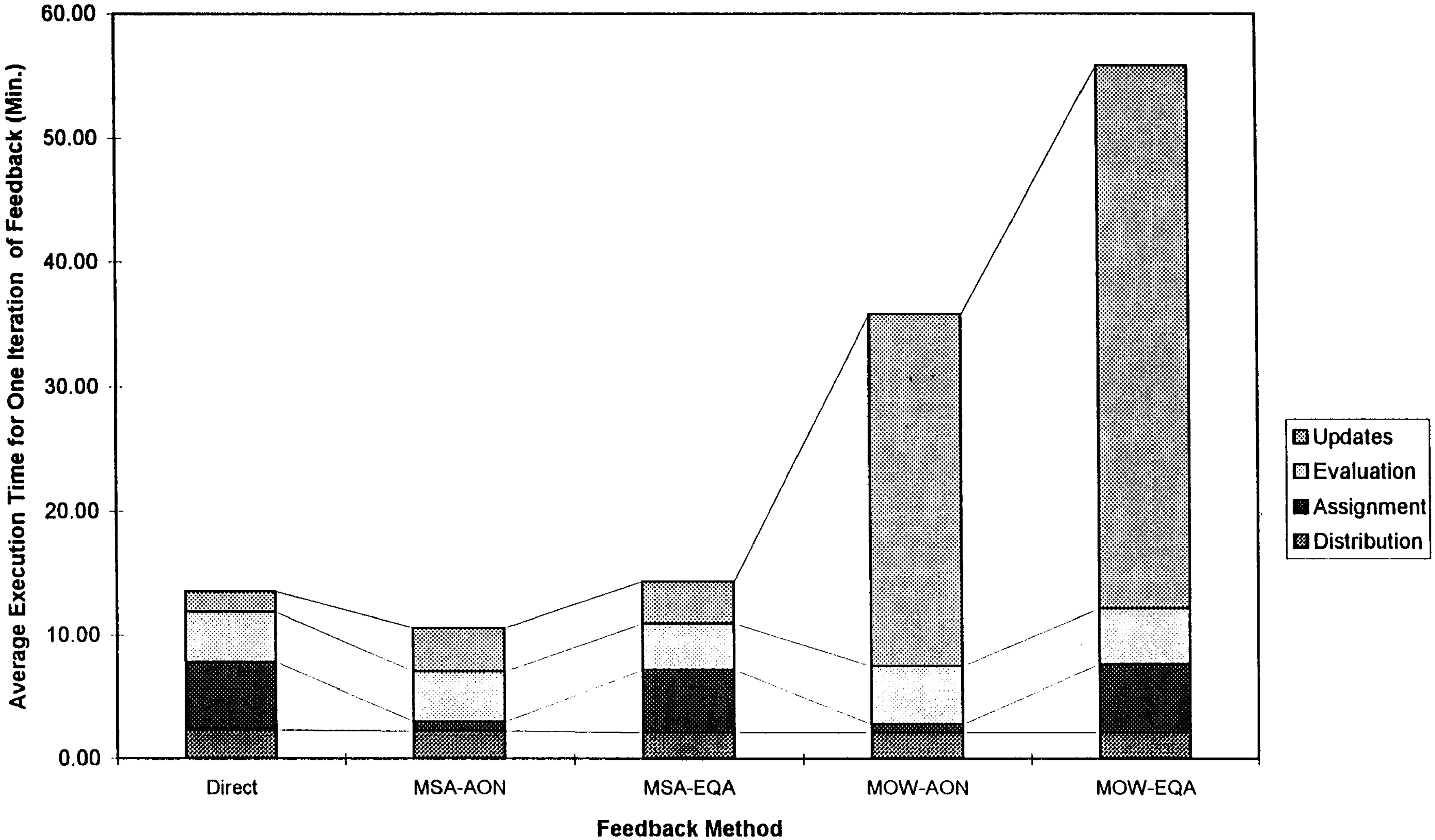


Figure 4.6: Comparison of Execution Times for Alternative Feedback Methods: RMS of Volume Versus Execution Time (in Minutes) Salt Lake City Model

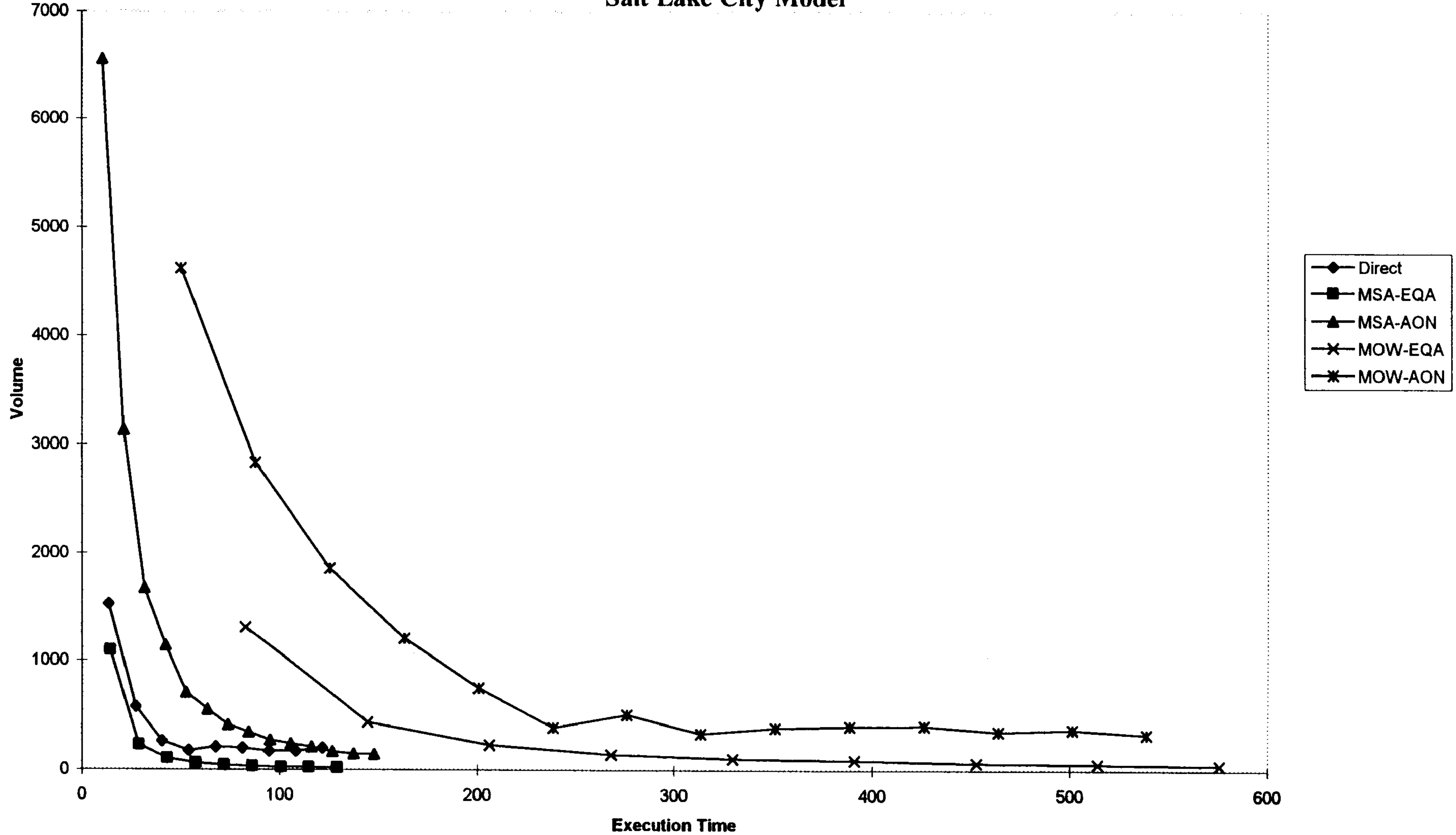


Figure 4.7: Comparison of Execution Time for Alternative Feedback Methods: Percent Change in Average Speed Versus Execution Time (in Minutes) Salt Lake City Model

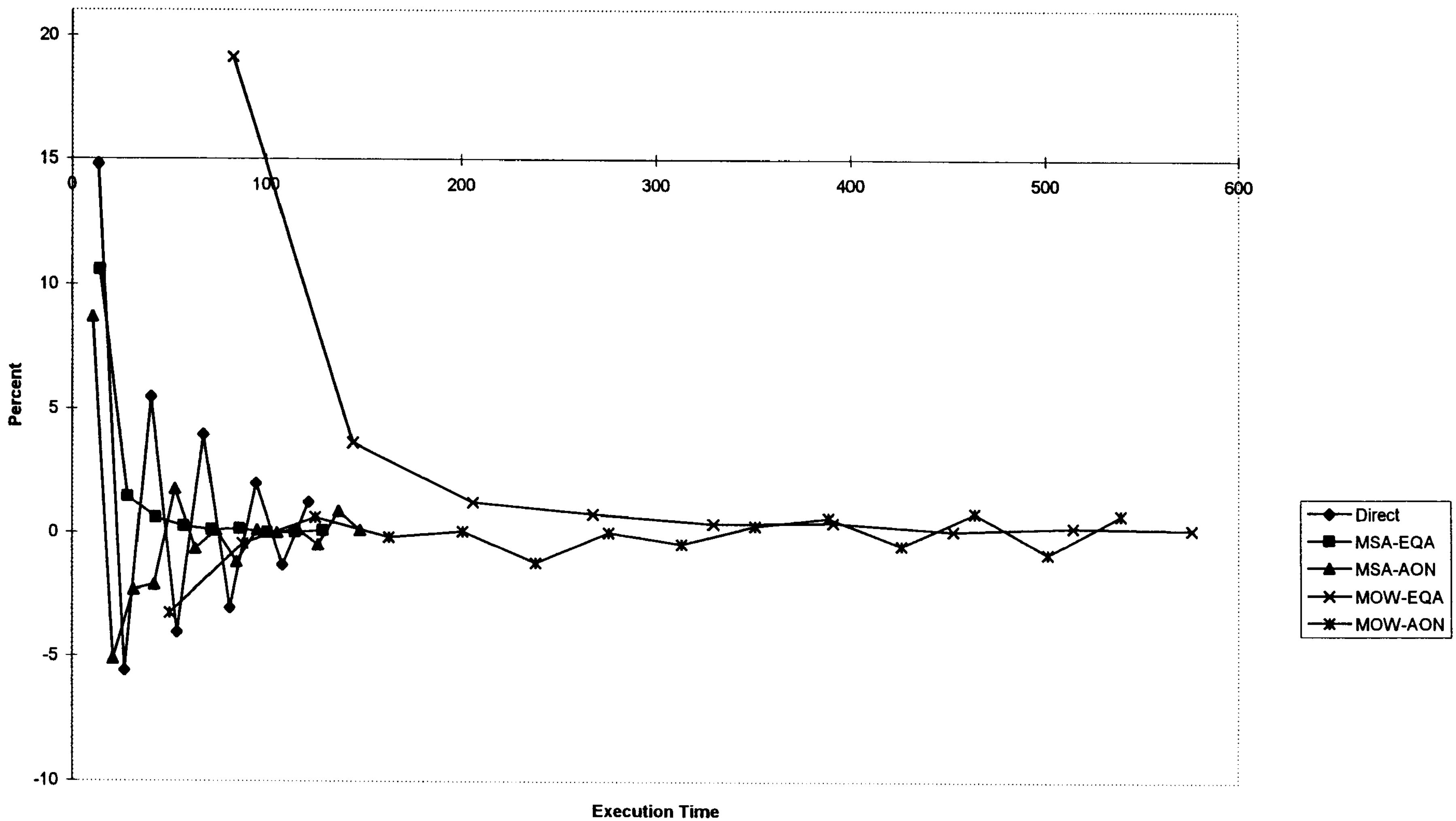


Figure 4.8: Comparison of Execution Time for Alternative Feedback Methods:
Maximum Absolute Change in Person Trip Impedance between O-D Pairs Versus Execution Time (in Minutes)
Salt Lake City Model

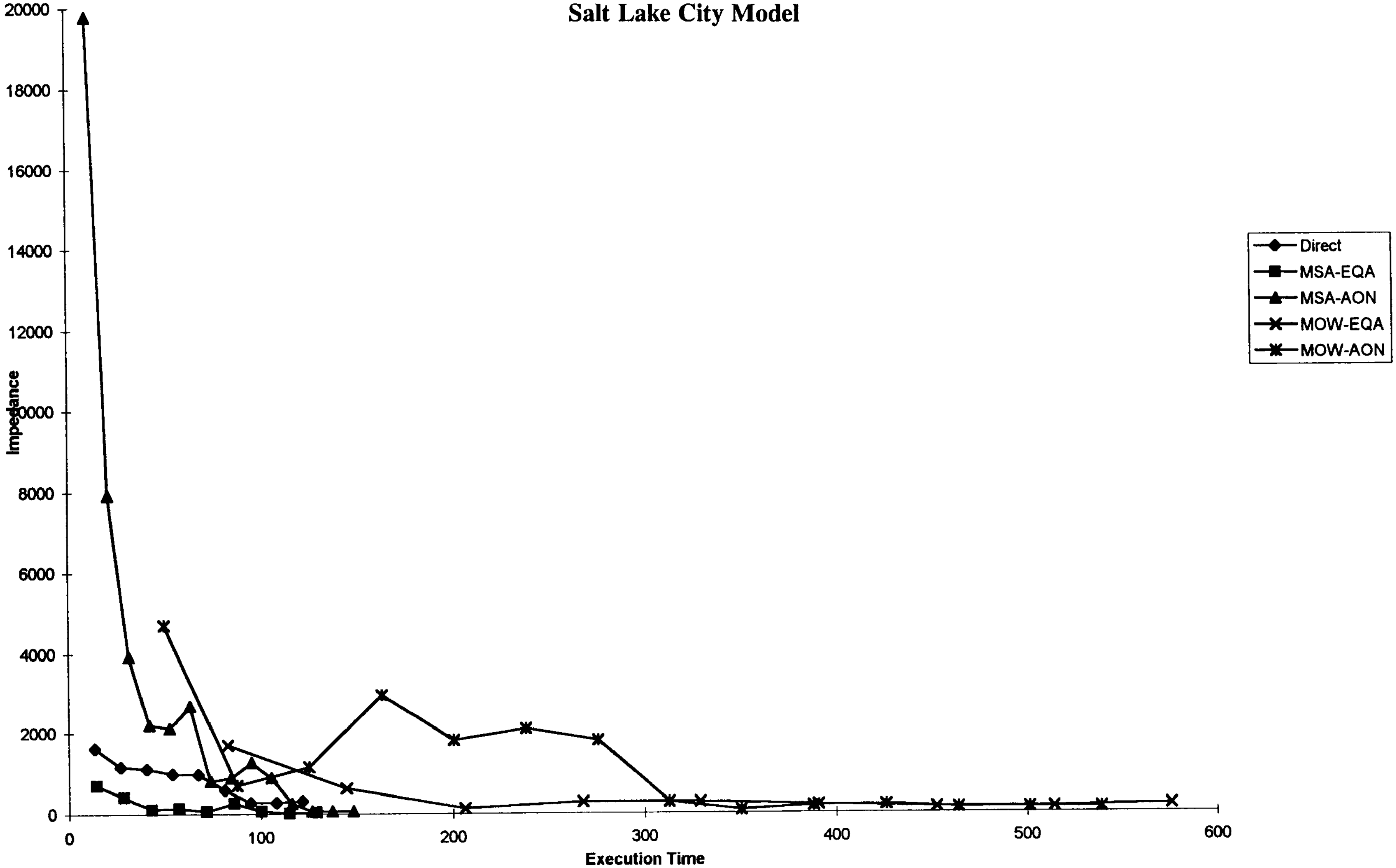


Figure 4.9: Location of New Facility Tested in Memphis Model

Figure 4.10: Location of New Facility Tested in Salt Lake City Model

Each of these scenarios was tested using three of the feedback mechanisms: the Direct Method, MSA-AON and MSA-EQA. They were then compared with the no-feedback case to evaluate the introduction of feedback under different conditions and methods.

Table 4.2 presents the baseline results from application of the Direct Method and the two MSA options for an "assignment to trip distribution" feedback loop in the two test case cities[1]. Using system-wide average speed as a measure of effect, the results of the two case studies indicate that feedback can produce significantly different results when congested conditions occur, but has very little effect where there is little or no congestion. In the Salt Lake City model, in which the average baseline speed without feedback was roughly 22 miles per hour, all three of the feedback methods produced system-wide speed increases between 21 and 23 percent for the baseline year. But for the Memphis metropolitan area, where the system-wide average speed without feedback was roughly 42 miles per hour, feedback produced a system-wide increase of less than two percent. Even when 25 percent uniform growth was added in the Memphis model, the increase in system-wide average speed over the no-feedback baseline was less than 3 percent. In the more congested Salt Lake City model system, 25 percent growth produced a difference of roughly 50 percent in system-wide speed between the no-feedback baseline and the three alternative feedback mechanisms. When the growth was concentrated radially, there was an even greater difference between the no-feedback baseline and the three alternative feedback methods.

Table 4.3 reflects a somewhat similar pattern of change in results from feedback where the system-wide vehicle miles traveled is the measure. Because the feedback loop tested in Memphis and Salt Lake City allowed for the use of an equilibrium set of travel times in the trip-distribution step, a different trip-length distribution could result for a fixed number of total vehicle trips. In both cases, feedback resulted in a reduction of system-wide vehicle miles traveled reflecting shorter mean trip lengths. Again, the change produced by feedback is significantly greater in the more congested Salt Lake City model (a reduction ranging from 11.5 percent to 12.5 percent) than in the Memphis model (where the change ranged from 2.2 percent to 2.5 percent).

---

1 Because of the specific characteristics of the test-case models, the Method of Optimal Weighting could not be tested for its effect on system-wide travel characteristics. When applied in the Salt Lake City model, the basic model parameters were changed to accommodate application of the feedback method and so the resulting output could not be compared with the "no feedback" output.

Table 4.2: Effects of Feedback on Model Systemwide Average Network Speed

Feedback		Test Scenario			
Method	Number of Iterations	Base	25% Uniform Growth	25% Radial Growth	New Facility
Memphis		Percent Change from "No Feedback" Speed	Percent Change from "No Feedback" Speed	Percent Change from "No Feedback" Speed	Percent Change from "No Feedback" Speed
No Feedback	1	41.6 mph	39.4 mph	39.1 mph	43.3 mph
Direct	10	1.1%	2.4%	2.9%	0.01%
MSA (Equil)	10	1.1%	2.4%	2.1%	0.01%
MSA (A-O-N)	15	1.3%	2.5%	2.1%	0.01%
Salt Lake					
No Feedback	1	22.0 mph	14.4 mph	12.9 mph	23.5 mph
Direct	10	22.8%	47.8%	62.6%	13.10%
MSA (Equil)	10	21.3%	48.2%	66.6%	12.60%
MSA (A-O-N)	15	23.0%	50.2%	68.1%	14.40%

Note: For No Feedback Case the Average Network Speed is shown. For the Direct and Method of Successive Averages cases the % Change from No Feedback is shown.

Table 4.3: Effects of Feedback on Model Systemwide Vehicle Miles Traveled

Feedback		Test Scenario			
Method	Number of Iterations	Base	25% Uniform Growth	25% Radial Growth	New Facility
Memphis		Percent Change from "No Feedback" VMT	Percent Change from "No Feedback" VMT	Percent Change from "No Feedback" VMT	Percent Change from "No Feedback" VMT
No Feedback (VMT)	1	15,824,577	19,559,521	19,849,273	16,273,549
Direct	10	-3.5%	-5.0%	-5.5%	-3.2%
MSA-EQA	10	-3.2%	-4.7%	-5.1%	-2.9%
MSA-AON	15	-3.6%	-5.0%	-5.4%	-3.1%
Salt Lake					
No Feedback (VMT)	1	17,796,907	22,668,632	22,794,044	18,004,694
Direct	10	-12.5%	-12.0%	-12.1%	-6.7%
MSA-EQA	10	-11.6%	-11.1%	-11.5%	-6.1%
MSA-AON	15	-11.5%	-10.8%	-11.2%	-6.0%

Note: For No Feedback Case the Vehicle Miles Traveled is shown. For the Direct and Method of Successive Averages cases the % Change from No Feedback is shown

The sensitivity testing with the two test-case models demonstrated a consistency in the nature and direction of change produced by the introduction of feedback. Although not all of the impacts of feedback on system characteristics are reported here, the tests indicated that feedback produced the following changes in assignment results:

- Average link speeds are increased,
- Average travel time is decreased,
- Average trip length is decreased,
- Average Volume/Capacity ratio is decreased, and
- Total vehicle miles travel is decreased.

While the direction of change was consistent in the observed results, the magnitude of the change for each of the above measures varied significantly and was almost always directly related to the amount of congestion in the network being modeled: the greater the level of congestion, the greater the change introduced by feedback. The systematic changes in results produced by the introduction of feedback have two significant implications. The first is the need for recalibration of a baseline model after feedback has been introduced into the modeling system. The second is the need for the use of feedback to reflect accurately the level of impact of increasing congestion on trip distribution and travel speeds.

4.4 Introduction of Mode Choice into the Feedback Process

Tests were conducted introducing mode choice into the feedback process for both the Memphis and Salt Lake models. Three cases were examined for each city:

- No feedback with mode choice using congested impedances

- Option 1: Feedback with default person-to-vehicle factors and post-feedback mode choice.

- Option 2: Feedback with integrated mode choice.

The Method of Successive Averages with Equilibrium Assignment (MSA-EQA) was the feedback mechanism used for the feedback tests. In Option 2 the initial travel times for both auto and transit were based upon free-flow conditions. For each iteration the transit in-vehicle travel times were estimated using a factor to increase auto travel time to account for the additional stops and dwell times of the transit vehicles.

For the MSA-EQA with integrated mode choice the same principles were used for updating the results for each iteration as those described in Chapter 3. At the end of each iteration the resultant link volumes and trip tables from the iteration's distribution and assignment are averaged with previous iterations results. The new travel times are then derived by applying the volume delay functions to the new averaged link volumes.

Summaries of the results for the different tests are shown in Tables 4.4 (Salt Lake City) and 4.5 (Memphis). In both models the transit mode share decreases from the "no feedback" case to "feedback with post-feedback mode choice." In Salt Lake City the transit trips drop 3.3 percent. In Memphis only a very small decrease of 0.8 percent was observed. The transit trips drop again between the "feedback with post-feedback mode choice" and the "feedback with integrated mode choice" tests. In this case, however, the transit trips in Salt Lake fell by only .6 percent, and virtually no change was observed in Memphis (a drop of 27 trips or 0.1 percent). In both cases most of the impact of feedback on transit trips was captured by using the default person-to-vehicle conversion factors and applying mode choice after equilibrium between distribution and assignment is reached. Salt Lake City has much higher congestion levels than Memphis (Average volume/capacity ratio of .98 versus .50), and also shows much greater differences in the impact of where mode choice is introduced.

The impacts on the average statistics are also most noticeable between the "no feedback" and "feedback with post-feedback mode choice" tests. Average speeds increase, and travel times and distances drop due to the shifting of trips away from the congested corridors. The transit mode share in the case studies is not high enough to provide a noticeable change in the daily congestion at the regional level. When "integrated mode choice" is introduced, the average speed continues to increase in Salt Lake probably due to some influence of the removal of long vehicle trips to the CBD in the transit corridors. The overall trip length and travel time also increase slightly over the previous feedback test where the default conversion factors were used. There is no significant change in speed in Memphis due to the lower congestion levels, however, a slight lengthening of travel times and distances is also observed.

Table 4.4: Comparison of Mode Choice Feedback Options for Salt Lake City

	Mode Choice with No Feedback	Post-Feedback Mode Choice	Feedback with Integrated Mode Choice
Person Trips by Mode			
Auto	3,188,247	3,188,727	3,189,991
Transit	43,734	42,254	41,990
Total	3,231,981	3,231,981	3,231,981
Average Statistics			
Average Speed (mph)	22.02	26.72	30.17
Average Trip Time (minutes)	18.15	16.23	17.20
Average Trip Length (miles)	6.40	5.92	6.07
Execution Time (minutes)	108	244	1,085

[1] The feedback method was MSA with equilibrium assignment.

Table 4.5: Comparison of Mode Choice Feedback Options for Memphis

	Mode Choice with No Feedback	Post-Feedback Mode Choice	Feedback with Integrated Mode Choice
Person Trips by Mode			
Auto	3,138,128	3,138,301	3,138,328
Transit	24,661	24,488	24,461
Total	3,162,789	3,162,789	3,162,789
Average Statistics			
Average Speed (mph)	41.60	42.07	42.07
Average Trip Time (minutes)	8.92	8.76	8.75
Average Trip Length (miles)	6.13	6.04	6.09
Execution Time (minutes)	6	71	103

[1] The feedback method was MSA with equilibrium assignment.

Incorporating full mode choice, including updating of the transit times and skims, increases the execution time significantly. In the Salt Lake City Model the execution time increased from 244 minutes (4.06 hours) for 10 iterations of feedback followed by mode choice to 1,085 minutes (18.1 hours) for 10 iterations of feedback with integrated mode choice. This is a 345 percent increase in execution time. In Memphis, a similar pattern is observed but the change is not as significant due to Memphis's simpler mode choice model formulation. Ten iterations of feedback followed by mode choice took 71 minutes (1.18 hours) in Memphis and this increased to 103 minutes (1.71 hours) with integrated mode choice. This was a 45 percent increase in execution time.

Because transit and HOV facilities tend to be concentrated along corridors, incorporating mode choice within the feedback process may have geographic impacts. To assess the geographic impacts, changes in district-to-district person trips between the different feedback mode choice options were also examined. Figure 4.11 provides a map of the districts used for this analysis. The district-to-district person trips for the base "no feedback" case and the ratio of the person trips between "feedback with post-feedback mode choice" and "feedback with integrated mode choice" are shown in Table 4.6. The trips shift to the suburban locations between the "no feedback" and "feedback with post-feedback mode choice tests". The attractions to the "North" district increase overall by 2 percent and "North" to "North" increases by 4 percent. Shorter trips within districts or to districts that are close to one another tend to increase while trips from the outer areas to the CBD, or between districts far apart decrease. "North" to the "CBD" decreases 2 percent, "Southwest" to the "CBD" decreases 8 percent and "University" to "North" decreases 30 percent.

Interestingly, the shift in trips continues to occur when the "feedback with integrated mode" choice is introduced. "North" to "North" increases 8 percent from the base "no feedback" case. "North" to the "CBD" decreases by 12 percent, and "Southwest" to "CBD" decreases by 17 percent. The greatest changes again occur from the congested areas out to the suburbs with the "University" to "North" trips decreasing by 45 percent and the "CBD" to "North" trips decreasing by 36 percent.

One of the main reasons that the two feedback processes have different impacts lies in the accuracy of the default person-to-vehicle factors that are applied in both the "no feedback" and "feedback with post-feedback mode choice" cases. In the Salt Lake City model, a single factor is applied to all trips for each purpose. No account is made for the existence of transit service or carpooling into the heavily congested areas. When a mode choice model is applied during each iteration, the vehicle trips are likely to be lower (less congestion) in the transit corridors, and higher (more congestion) in the suburban areas.

Several important observations can be made from this analysis:

- It is very important to re-validate the mode choice models and match observed transit trips between areas when feedback is introduced regardless of where mode choice is in the process.

Figure 4.11: Salt Lake City Model Superdistrict System

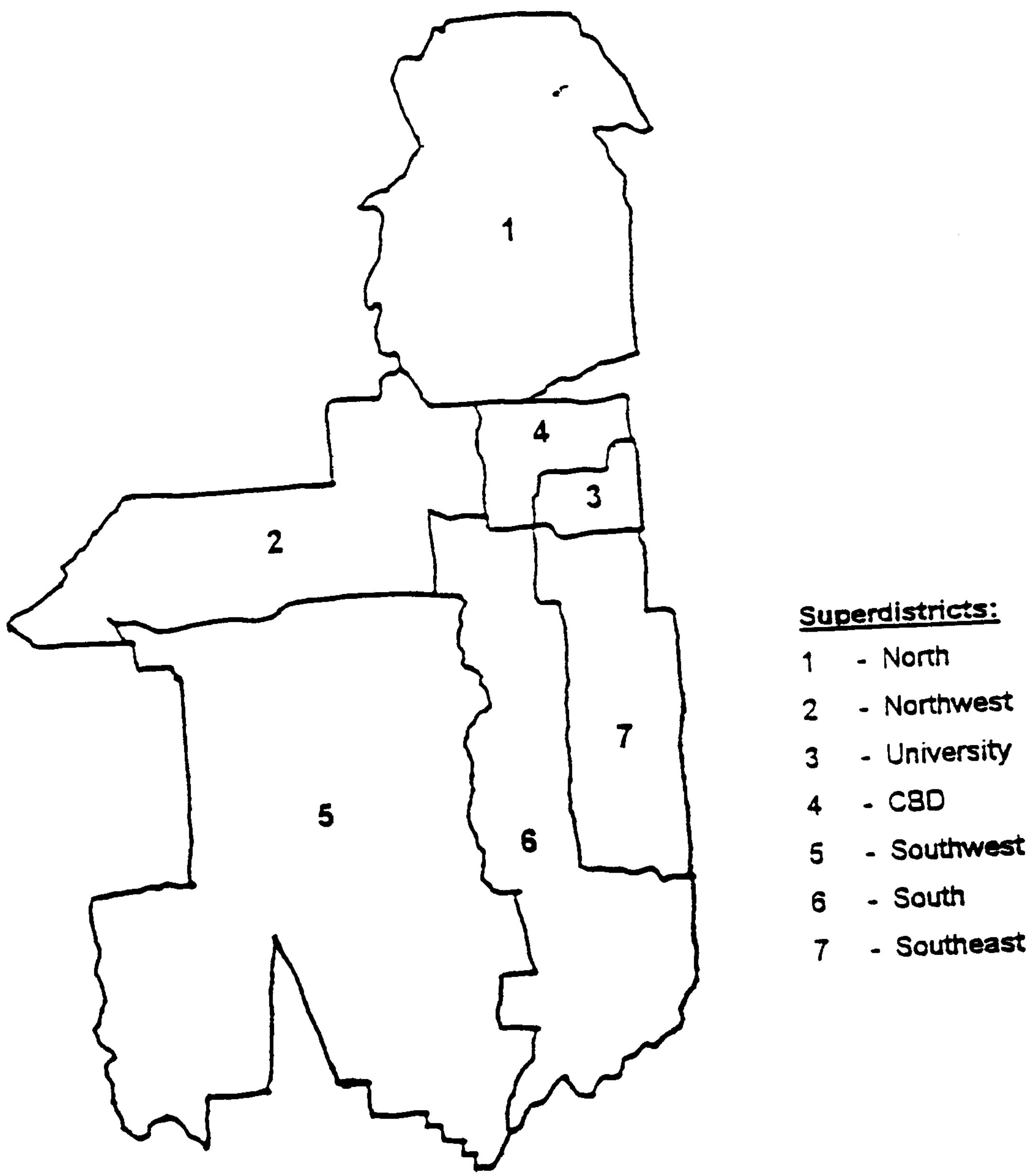


Table 4.6: District to District Impacts of Feedback and Mode Choice
Salt Lake City No-Feedback Model
Person Trip Table

Destination District

		1	2	3	4	5	6	7	8	Total
1	NORTH	192,429	42,523	17,482	38,839	11,602	20,961	6,502	0	330,338
2	NW	7,086	61,255	9,687	40,157	18,099	26,551	6,585	0	169,420
3	UNIV.	1,876	9,756	61,036	46,488	4,716	19,878	22,509	0	166,259
4	CBD	4,401	25,183	28,527	115,776	7,621	31,856	14,338	0	227,702
5	SW	7,910	91,397	30,920	61,133	597,163	211,723	52,012	0	1,052,258
6	SOUTH	7,588	60,248	55,754	101,431	119,430	550,848	158,589	0	1,053,888
7	SE	4,462	32,038	105,706	80,433	49,634	226,618	334,826	0	833,717
8	OTHER	15,977	34,674	15,360	48,166	51,741	75,747	40,626	0	282,291
	Total	241,729	357,074	324,472	532,423	860,006	1,164,182	635,987	0	4,115,873

Salt Lake City MSA Feedback Model with Post MS
Percent Change in Trips From Base No Feedback

Destination District

		1	2	3	4	5	6	7	8	Total
1	NORTH	3.8%	-5.8%	-8.9%	-7.9%	-2.3%	0.5%	0.7%		0.0%
2	NW	-6.6%	-2.9%	3.7%	3.1%	-7.5%	6.2%	7.1%		0.1%
3	UNIV.	-30.1%	-6.7%	13.7%	2.1%	-27.1%	-15.0%	-17.2%		0.0%
4	CBD	-20.4%	-2.9%	5.7%	2.2%	-13.6%	-1.8%	-6.7%		0.0%
5	SW	-4.2%	-2.1%	-13.0%	-7.6%	3.8%	-5.0%	-3.2%		0.0%
6	SOUTH	-5.6%	9.7%	-5.3%	2.3%	-10.5%	1.1%	1.3%		0.0%
7	SE	-10.3%	11.2%	-3.4%	0.8%	-9.9%	1.4%	0.5%		0.0%
8	OTHER	-0.4%	0.0%	-0.2%	0.0%	0.1%	0.1%	0.1%		0.0%
	Total	1.7%	0.5%	-0.6%	0.0%	0.2%	-0.3%	-0.3%		0.0%

Salt Lake City MSA Feedback Model with Integrated Mode Choice
Percent Change in Trips From Base No Feedback

Destination District

		1	2	3	4	5	6	7	8	Total
1	NORTH	8.1%	-13.6%	-15.4%	-12.8%	-10.2%	-4.4%	-3.8%		0.0%
2	NW	-17.7%	-2.5%	4.8%	4.9%	-15.1%	9.0%	10.2%		0.0%
3	UNIV.	-45.0%	-15.7%	21.0%	4.0%	-39.3%	-23.5%	-26.2%		-0.1%
4	CBD	-36.7%	-11.6%	7.1%	7.1%	-28.4%	-4.8%	-16.2%		-0.1%
5	SW	-10.2%	2.0%	-9.9%	-17.1%	7.7%	-12.2%	-16.3%		-0.1%
6	SOUTH	-16.6%	12.5%	-9.3%	2.4%	-20.3%	4.6%	-3.2%		-0.1%
7	SE	-22.2%	19.7%	-9.2%	-2.6%	-21.2%	-0.1%	5.1%		0.0%
8	OTHER	-0.4%	-0.1%	-0.1%	-0.1%	0.1%	0.1%	0.1%		4.2%
	Total	3.7%	1.1%	-1.7%	-0.6%	0.4%	-0.5%	-0.7%		0.2%

- One of the most significant impacts of using feedback with integrated mode choice is the increase in computational time. Thus, the benefits of performing a mode choice calculation needs to be weighed carefully. It may not be worth integrating mode choice unless transit/carpool use significantly impacts the highway travel times typically used in trip distribution.

- In feedback with post-feedback mode choice, using the default person-to-vehicle conversion factors is very important to the process. At a minimum, a matrix based upon observed, or projected, mode shares and person-to-vehicle ratios should be used. Otherwise the geographic impacts may be significant.

4.5 The Effect of Feedback on Model Sensitivity

Previous sections of this chapter have demonstrated how feedback can affect the results of a model when there is congestion in the network being modeled. The comparisons made in the previous sections were for prescribed baseline conditions, however, and merely suggest the need to recalibrate a model to match observed travel characteristics for those baseline conditions. Once recalibrated, the model with feedback would generally produce travel characteristics for the baseline condition similar if not identical to those of the model without feedback. The true test of the effect of feedback on the output of a modeling system must be based on the difference in results from forecasting with a recalibrated model with feedback and a calibrated model system without feedback.

The resources of this research project did not allow for a full recalibration of either of the test-case models with feedback incorporated. As a result, a true test of the model sensitivity in forecasting is not possible. A reexamination of the results of the sensitivity tests for the Memphis and Salt Lake City models can provide a useful indication of the effect of feedback on sensitivity of forecasts, however, by comparing the percent change from baseline to the conditions of the sensitivity tests (25 percent uniform growth, 25 percent radially concentrated growth and a new facility). For the model without feedback and for each of the models with feedback, the differences in percentage change provide an indication of how sensitive the model alternatives are to changes that would produce more or less congestion in the network.

Table 4.7 provides a comparison for three system-wide performance measures: average speed, vehicle miles traveled, and average V/C ratio. The results presented in the table suggest that the model with feedback is less sensitive to growth or to strategies designed to reduce congestion.

In both model systems, the test of the high-growth scenarios produced less decrease in average speed and less increase in average V/C ratio in the models with feedback than in the models without feedback. This was true for both the uniform growth scenario and the radially-concentrated growth scenario. The test of a major new roadway facility produced a decrease in congestion (as reflected in the reduction in average V/C ratio and the increase in average speed) for all of the models, but the decrease in congestion was less in the models with feedback than in the models without feedback.

A similar conclusion of less sensitivity in the model with feedback does not appear appropriate for the effects on VMT. Unique location-specific characteristics can, in some cases, contradict the conclusion. As illustrated in Table 4.7, the addition of a major new roadway facility produced an increase in VMT in all of the models, but the increase in VMT in the models with feedback was slightly more than in the models without feedback.

The conclusions on the sensitivity of models with feedback suggest that a recalibrated model with feedback may provide a better representation of speeds and travel times but may show less benefit from projects designed to reduce congestion or improve speeds. Likewise, models with feedback will probably show less deterioration of speed and less overall congestion as a result of growth in trips and VMT.

Table 4.7 Effects of Feedback on Model Sensitivity

Change in Model Systemwide Average Speed from Baseline

Method	25% Uniform Growth	25% Radial Growth	New Faciltiy
Memphis			
No Feedback	-5.2%	-5.9%	4.1%
Direct	-4.0%	-4.3%	3.5%
MSA (Equilibrium)	-4.0%	-5.0%	3.5%
Salt Lake			
No Feedback	-34.5%	-41.5%	7.6%
Direct	-18.1%	-19.5%	2.9%
MSA (Equilibrium)	-16.8%	-16.5%	3.7%

Change in Model Systemwide V/C Ratio from Baseline

Method	25% Uniform Growth	25% Radial Growth	New Faciltiy
Memphis			
No Feedback	23.7%	25.4%	-8.0%
Direct	21.7%	22.7%	-6.6%
MSA (Equilibrium)	21.8%	22.9%	-6.8%
Salt Lake			
No Feedback	27.2%	27.0%	-2.6%
Direct	20.8%	21.1%	-1.1%
MSA (Equilibrium)	22.1%	22.2%	-1.1%

Change in Model Systemwide Vehicle Miles of Travel from Baseline

Method	25% Uniform Growth	25% Radial Growth	New Faciltiy
Memphis			
No Feedback	23.6%	25.4%	2.8%
Direct	21.7%	22.8%	3.2%
MSA (Equilibrium)	21.8%	23.0%	3.2%
Salt Lake			
No Feedback	27.4%	28.1%	1.2%
Direct	21.4%	21.9%	2.2%
MSA (Equilibrium)	21.1%	21.1%	1.6%

5. GUIDANCE FOR IMPLEMENTATION OF FEEDBACK

There are a number of additional issues and concerns that the practitioner should be aware of when developing and using feedback applications. These include revalidation, resource requirements, the potential problems associated with integer arithmetic and round off error, zone size, starting conditions, assignment algorithms, component impedance function, hyper-sensitivity, and averaging. Each of these issues is addressed in this chapter.

5.1 Revalidation

> Issue: The introduction of feedback changes some of the basic relationships within the four-step forecasting process. These include the definition of the impedance used in trip distribution and the inputs to mode choice, including the origin-destination flows and relationships between the auto and transit times and costs.

Any time a new feedback mechanism is introduced, the travel forecasting process must be revalidated. As an example, introducing congested times into the feedback between assignment and distribution will require re-examination of speeds and travel times, trip distribution friction factors, assignment parameters and mode choice parameters. These are each discussed below. If a previous forecasting application that validated to base conditions exists, the new models with feedback can be adjusted to match the previous forecast but the more desirable option is to validate the observed condition when the data are available.

> **Speeds/Travel Times.** As discussed in earlier sections, one of the important reasons for introducing feedback is to insure that the speeds and travel times used throughout the process are consistent and **reflect actual operating conditions**. This allows the models to correctly represent travelers responses to congestion and to provide realistic speed data to the emissions models such as MOBILE. It is important, therefore, to validate the resultant speeds from the feedback models to observed speeds. Speed data are difficult to acquire and may have to be collected as part of a special study. One source of information in areas with TMAs (200,000+ population) is the information in the ISTEA management systems called for to support the Congestion Management and Traffic Monitoring Systems.

> **Trip Distribution (Friction Factors).** Changing the trip distribution impedances from look up tables to those calculated directly from the flows on the network has a number of impacts.

First, it provides much more variation and difference by direction between origin-destination pairs than is possible from look up table values. The time matrixes can capture the difference between the inbound and outbound travel times to the CBD in the morning to suburban locations. Second, the times will be more reflective of the operating differences along a route. Third, the average values may vary by area making parts of the network more or less accessible. Each of these points suggest the need to revalidate the trip distribution friction factors in parallel with the final travel times/speeds. A process to validate the friction factors of a gravity model is provided in *Calibrating & Testing A Gravity Model For Any Size Urban Area* (FHWA, 1983). If a trip table from a previously validated model exists, Table 5.1 defines the steps that can be performed to adjust the friction factors after introducing feedback. Adjustment of friction factors in each iteration is desirable but adjustment in the final application of distribution is necessary as a minimum.

As examples of the need to revalidate trip distribution, friction factors for Memphis and Salt Lake City were re-adjusted with the introduction of the MSA-EQA procedures. Again, the Memphis base case had relatively little congestion and the introduction of feedback had little impact on the trip distribution. With feedback, average speed increased from 41.6 to 42.1 mph (1 percent growth), and the average trip length decreased from 6.10 to 6.04 miles. The friction factors were adjusted to match the trip length frequency of the original trip tables applied to the travel time skims from the new MSA-EQA assignment.

The Salt Lake City base case had a V/C ratio of 0.98, and introducing feedback into the model caused the average speed to increase from 22.0 to 26.7 (21 percent), and the average trip length to shift from 6.40 to 5.92 (-7.47 percent) miles. The resulting VMT also decreased 12 percent. This is a significant change that could lead to large differences in the emission estimates and other analyses that depend upon VMT and speed. Because of the large shift it was difficult to replicate the trip length frequency of the original trip table using the new travel time skims from the MSA-EQA assignment.

Assignment. The assignment should also be re-examined because feedback can change travel patterns by redefining impedance relationships. At a minimum the cordon around major destinations such as the CBD should be examined to insure that existing observed travel patterns are not being distorted. Normal assignment validation checks on RMSE to ground counts, screen line validation, and VMT estimates should also be made. The expanded data from the ISTEA Traffic Monitoring Systems and HPMS plus local traffic counts are possible sources for data to check the road volumes. The forecasting models must produce VMT estimates consistent with HPMS for conformity analysis.

Mode Choice. As previously stated, when feedback was introduced in the Washington, D.C. region, MWCOG's simulations produced 20 percent fewer HOV trips and 11 percent fewer auto access to transit trips. It is likely that this was caused both by a shift in person trips away from the congested radial transit markets and by an improvement in the simulated highway travel times. This example highlights the need to re-validate the mode choice processes even if only the highway-assignment-to-trip-distribution feedback is being introduced. The impacts of

Table 5.1 Steps to Adjust Existing Trip Distribution Factors with the Introduction of Feedback

<table>
<tr><td>STEP 1.</td><td>Obtain target trip table from existing model application or survey data.</td></tr>
<tr><td>STEP 2.</td><td>Execute the model application with feedback included allowing it continue until convergence is reached.</td></tr>
<tr><td>STEP 3.</td><td>Skim the travel times/impedances using the final assigned volumes from Step 2. If an averaging procedure is being used to update the volumes after each iteration make sure that the volumes are those from the final adjustment.</td></tr>
<tr><td>STEP 4.</td><td>Obtain the trip length frequency of the target trip table using the travel times/impedances from Step 3.</td></tr>
<tr><td>STEP 5.</td><td>Obtain the trip length frequency of the modeled trip table using the travel times/impedances from Step 3.</td></tr>
<tr><td>STEP 6.</td><td>Obtain a new set of friction factors using the following formula.
$$F_{adj\ t_i} = F_{used\ t_i}\left(\frac{OD\%_i}{GM\%_i}\right)$$
Where:
$F_{adj\ t_i}$ = Friction Factor to be used in next run
$F_{used\ t_i}$ = Friction Factor used in current run
$OD\%_i$ = % of trips in time increment i from target trip table
$GM\%_i$ = % of trips in time increment i from modeled trip table</td></tr>
<tr><td>STEP 7.</td><td>Plot the adjusted friction factors with respect to time and check for reasonableness. The final curve should be smooth and always decreasing. An alternative is to fit the adjusted friction factors to a known function using regression. Two common functions used are the Exponential and Gamma Functions shown below:
$$F_{exponential} = a\ e^{-\alpha t_{ij}}$$
$$F_{gamma} = a\ t_{ij}\ e^{-\alpha t_{ij}}$$
Where:
a, α = calibrated constants
t_{ij} = travel time or impedance between origin i and destination j</td></tr>
<tr><td>STEP 8.</td><td>Return to Step 2 and repeat until adjustments are no longer necessary.</td></tr>
</table>

integrating a full transit reevaluation (new transit times and mode choice) within each iteration continue to produce changes in trip distribution and transit use. In the test cases, however, it was observed that the most significant changes in transit use occurred with the simple introduction of assignment-distribution feedback and a performing full mode choice run once the convergence had been reached. When an integrated mode choice process was included in each iteration, the changes in trip distribution continued but with only slight additional impacts on the transit ridership or systemwide average performance characteristics. In either case a revalidation of the mode choice models is necessary when feedback is introduced.

Recommendation: Revalidation of the travel forecasting process must be performed with the introduction of feedback. Even if only an assignment-distribution feedback loop is included, the basic relationships and travel patterns that result will change. All steps of the forecasting process should, therefore, be examined for revalidation including trip distribution (friction factors and cordon/screenline assessment), assignment, and mode choice.

5.2 Resource Requirements (Time and Storage)

Issue: The resource requirements (time and storage) to execute feedback can quickly become excessive.

Due to the repetitive nature of feedback, the resource requirements required to execute full feedback runs can become excessive and can become a critical factor in determining where in the four-step process to implement feedback loops and what mechanisms to implement. Storage requirements are a function of the number of zones and matrixes that need to be used or saved by the process. The requirements grow approximately with the square of the number of zones and the number of executions that are made. The storage requirements for one iteration of Salt Lake City and Memphis are shown in Table 5.2.

Table 5.2 Storage requirements for the Results of One Iteration

Execution of the Four-step Process			
Test Case	Number of zones	Highway datasets	Mode choice datasets
Memphis	381	4,960,000 Kb	1,891,680 Kb
Salt Lake	585	6,250,000 Kb	30,500,000 Kb

The simplest approach for processing the data when using feedback would be to save each iteration's results (trip tables, assigned networks, travel time matrices, etc.) and process them at the end of the run to obtain final values. This would place an undue resource requirement on the travel forecasting process for all but the smallest of regions. For example, preserving results from 10 iterations for Salt Lake City when mode choice is included within the feedback process would require 360 Mb of storage. It should be noted that the storage requirements depend upon the specific forecasting application being implemented. Salt Lake City has a more fully specified mode choice model that requires both more storage and more time to execute.

Time of execution is also an important consideration when producing travel demand forecasts. With a very congested forecast-year network, Walker reports that for the 1449 zone Philadelphia region the execution time for five iterations of feedback using a 66 MHZ 486 PC (a powerful computer at the time of the study) took 78 hours for the Direct Method; 79 hours for MSA-EQA; 15 hours for MOW-AON; and 26 hours for MOW starting with a full equilibrium assignment for the speed, and then proceeding with all-or-nothing (Walker, 1995). A new process now being developed for the Washington D.C. area that includes the development of composite utilities and feedback through trip generation takes approximately 192 hours to execute two iterations. These execution times show the importance of carefully weighing the advantages and disadvantages of incorporating feedback at different locations in the forecasting process.

Where and how the different portions of the four-step process are fed back can radically change execution times. This is illustrated in Table 5.3 which provides the execution times for the Memphis and Salt Lake City test cases by component using Pentium computers (Some variation is observed due to the use of several Pentiums with speeds from 60 to 100 Mhz).

As shown, the execution times in the larger Salt Lake City system are approximately twice those for the Memphis system. There is little difference in running the Direct Method or MSA-EQA in terms of execution time. The choice of running MSA-EQA, or MSA-AON depends upon considerations other than execution time. The MSA equilibrium performs more assignments to the network, while the MSA-AON runs more iterations of trip distribution for the same approximate computer time. The changes between all-or-nothing assignments appear to be more volatile and from the test cases it appears that it may be beneficial to perform more assignments rather than more iterations through trip distribution, especially in small areas with relatively few zones. As the number of zones increases the number of paths and links assigned along the shortest path during each all-or-nothing assignment tends to increase as well and may cause the use of the MOW-AON or MSA-AON to be more appropriate.

In Table 5.3 it can also be seen that the transit skim and mode choice components of each test case can take the longest to execute of any of the individual elements in the forecast process. The transit skim and mode choice components take 58 and 42.4 minutes respectively in the Salt Lake City application. Combined, they require 92 percent of the execution time in the No-Feedback case. In Memphis they represent 46 percent of the execution time without feedback. How feedback is introduced for mode choice can significantly impact the time and resources required to produce a travel forecast. Options vary from 1) using default mode shares throughout the feedback iterations and once convergence is reached, using the congested highway times as inputs to mode choice, to 2) running new mode choice calculations each iteration but not updating the transit travel times (appropriate in a system where the majority of the transit system operates on dedicated facilities or at significantly lower speeds than the road system due to boardings and alightings), to 3) performing the full transit path building, skim, and mode choice calculations with each iteration. The full execution increased the execution time in Salt Lake City from 235 minutes (3.9 hours) to 1085 minutes (18 hours) for 10 iterations of MSA-EQA.

MOW can also add to the execution time because it requires conducting a line search using both the detailed information from each link and each origin-destination flow. The additional time may be exaggerated in the test case shown in Table 5.3 because extra calculations that would not exist in other applications were added to help evaluate the mechanism as part of the research effort.

Table 5.3: Effects of Feedback on Base Models Systemwide Execution Time

Feedback							Execution Time (in minutes)						
Mechanism	Number of Executions						Distribution	Transit	Mode Choice	Assignment	Updates	Evaluation	Total
Memphis	L	G	D	T	M	A							
No Feedback	1	1	1	1	1	4	1.3	2.2	0.7	2.3	0.0	0.0	6.4
Direct w. post ms	10	1	10	1	1	40	12.8	3.4	0.7	22.8	4.7	18.8	63.2
MSA-EQA w. ms	10	1	10	10	10	40	7.8	21.8	6.5	40.0	8.5	18.2	102.8
MSA-EQA w. post ms	10	1	10	1	1	40	12.3	3.4	0.7	22.3	13.7	18.7	71.0
MSA-AON w. post ms	15	1	15	1	1	15	17.0	3.4	0.7	7.3	18.3	26.0	72.5
Salt Lake													
No Feedback	1	1	1	1	1	7	2.3	58.0	42.4	5.5	0.0	0.0	108.2
Direct w. post ms	10	1	10	1	1	70	23.0	58.0	42.4	55.0	16.5	40.7	235.6
MSA-EQA w. ms	10	1	10	10	10	70	16.3	532.7	394.7	85.3	17.7	39.2	1085.8
MSA-EQA w. post ms	10	1	10	1	1	70	21.0	58.0	42.4	50.7	34.0	37.7	243.8
MSA-AON w. post ms	15	1	15	1	1	15	33.5	58.0	42.4	11.0	52.8	61.3	258.9
Evans-AON w. post ms*	15	1	15	1	1	15	36.0	58.0	42.4	11.3	1212.8	61.0	1421.4

The Evans' procedure and other MOW processes have also been reported to significantly reduce the iterations required to reach convergence (Walker 1995, Boyce, 1994).

> Recommendation: Execution time is not significantly different for MSA-EQA than for Direct feedback methods. Due to the more desirable features of MSA-EQA and MSA-AON, it is recommended that they be used instead of the Direct Method. MOW added to the execution time but may improve convergence performance in heavily congested networks.
>
> Recommendation: The transit components and mode choice add significantly to the execution time when incorporated within a feedback loop. Care should be taken to determine whether full incorporation of mode choice in feedback is warranted.
>
> Recommendation: To avoid excess storage requirements, develop each feedback mechanism to require only the current overall solution, and sub-problem solutions to execute. Provide the option to save intermediate iteration results in test or other special circumstances (see the section in this chapter on averaging issues).

5.3 Round Off Error and Integer Arithmetic

> Issue: The use of integer arithmetic and trip tables can lead to compound round-off errors in feedback and loss of precision in reaching the equilibrium solution.

When averaging of the trip tables in the MSA procedures, it is possible to obtain round-off errors that can compound, leading to changes in the trip tables that are being assigned between iterations. When a process was used in the research that did not bucket-round and control for the trips coming out of each zone or use real arithmetic, the trip tables tended to change between iterations simply due to the round-off error.

The compounded error can be seen in Table 5.4. For the Salt Lake City test of radial growth, the total number of trips increased by 6.3 percent using MSA-EQA without controlling for MSA-AON where more averages of the trip tables and less assignment passes are made, the error also increased but slightly less to 5.1 percent. In Memphis, the number of trips increased roughly 2.6 percent in both tests.

Table 5.4 Round-Off Error in Total Trips After Feedback

Test Case	Total Trips without Feedback	Total Trips with Feedback	Error
Salt Lake City Radial Growth			
MSA-EQA	5,140,265	5,462,894	6.3%
MSA-AON	5,140,265	5,408,636	5.2%
Memphis Radial Growth			
MSA-EQA	3,953,689	4,056,299	2.6%
MSA-AON	3,953,689	5,056,597	2.6%

There are a number of explanations for this difference. One of them is the increase in congestion between the two trip tables that are being averaged. Salt Lake City has higher congestion and therefore leads to more radical changes in the trip tables between the iterations of trip distribution. Memphis has little or no congestion and therefore the trip tables are more stable and there is less round-off error. Other factors may be the number of zones and the size of the area between the two case studies. It may not be possible to predetermine whether the round-off error will lead to either more or less trips in the trip tables that are being assigned, but it is very likely that they will be different.

Another issue of concern is that the processes for reaching equilibrium, such as the Frank-Wolfe or Evans Algorithm, assume continuous or real variables when solving for their optimal weight for averaging at the end of each iteration. Using integer trip tables can distort their results and lead to slower convergence or instability (Boyce, 1995; Van Vuren, 1995).

> Recommendation: Use real arithmetic for calculations and maintain trip tables until the final step or provide a bucket rounding technique that preserves the row or column totals during each averaging process.

5.4 Number of Zones and the Impact of Intra-Zonal Trips

Issue: A small number of zones may impact the stability of the All-or-Nothing assignment procedures, or produce a high percentage of intra-zonal trips and thus affect the feedback results.

Areas with a relatively small number of zones should be aware of the potential differences caused by some of the feedback mechanisms. When using the all-or-nothing assignment procedures with a relatively small number of zones, the assignments for each iteration tend to be lumpy and not smoothly distributed over many links. This can cause greater instability and fluctuations for areas using relatively few zones (less than 300). For areas with a large number of zones (1000 +) the All-or-Nothing assignments are more evenly distributed and this issue may disappear.

Another issue when using few zones in the application or when using a focused system with larger zones away from the study area is that the percent of trips that are intra-zonals must be taken into account for the proper feedback to trip distribution to occur. Lawton (1993) reports that "It is apparent that significant errors are introduced when a large proportion of the trip table entails intra-zonal trips (which are less sensitive to congestion effects)."

Recommendation: Use MSA-EQA with equilibrium assignment rather than MSA-AON except in special circumstances when the zone size is small.

5.5 Starting Conditions and Feedback Variables

Issue: The starting conditions and variables used for feedback can have a noticeable impact on the stability and convergence of feedback procedures.

Early on in the project, the research team tested a procedure that has been used by others in implementing feedback. The congested times were fed back and used as the initial (uncongested) travel time in the volume delay function rather than using the original free flow times to estimate the next impedance level. This practice led to unstable conditions, the assigned volumes tended to fluctuate especially in the Direct Method. Due to the nature of the volume-delay function, travel times are not allowed to improve from the initial time used for each iteration even if volume is shifted to less congested routes.

The starting conditions for the initial estimation of the origin-destination times also have an impact on the convergence. This research always started with initial free flow times to calculate the first set of origin-destination travel times. Others have suggested using estimated loaded times, but this should only be done when running a full equilibrium assignment.

Another option is to mix the types of assignment. Walker and Peng (1995) report that when a full equilibrium assignment is used for the first iteration in an MOW procedure and is then followed by using All-or-Nothing assignments for the remaining iterations, the convergence is improved over using All-or-Nothing assignments for all passes. The first equilibrium assignment produces more dispersed link flows closer to equilibrium than using an All-or-Nothing assignment to start.

> Recommendation: Freeflow conditions should always be used for the starting point in the volume-delay functions when applying feedback. The volume/capacity ratio from the overall solution is then used to update the link travel times.

5.6 Assignment Algorithms

> Issue: Different assignment methods other than equilibrium are in use in current forecasting applications in the U.S.

The two assignment algorithms explored as part of this research included equilibrium assignment and All-or-Nothing assignment for each iteration of the feedback process. The All-or-Nothing assignment within feedback simulates the equilibrium assignment with an additional trip distribution included in each update. Other assignment algorithms include incremental, stochastic, and stochastic equilibrium.

While the other assignment techniques were not fully investigated, some observations can be made. First, if effort is to be spent in updating a forecasting process, the assignment should also be updated to include, at a minimum, equilibrium assignment, or under special circumstances All-or-Nothing as part of the larger feedback problem. Second, Sheffi (1985) has shown that under congested conditions the equilibrium assignment produces similar results to stochastic user equilibrium assignment. Since feedback has its greatest impact in congested conditions, it seems that equilibrium assignment should provide good results, especially in future-year congested systems.

> Recommendation: Use an equilibrium assignment method for feedback except in special circumstances where the zone size is small and the network is very large and congested.

5.7 Composite Impedance Functions

> Issue: Trip distribution based upon highway impedances may not accurately capture all of the travel decisions made by travelers using other modes.

Composite impedance functions use the travel times and costs of each mode to develop an average zone-to-zone impedances for use in trip distribution. This can be an important feature when a significant portion of the trips in an area are made by alternative modes (transit or HOV) and especially if the alternative modes provide travel time or other advantages.

Composite impedances can add significantly to the processing time of a travel forecasting application because the times and costs must be skimmed for all modes for each trip distribution. As recently as 1992, however, the FTA guidance placed cautions on the use of composite impedance functions and their impact:

> ...In areas where transit captures only 30 percent of work trips to the downtown and 5 percent of all work trips, the significance of transit service on trip distribution is less certain. Absent any indication that a substantial difference in the forecasts is likely, it may not be worth the effort to incorporate sensitivity to factors other than highway travel time (FTA, 1992).

FTA did recognize that composite impedances may be important in large cities and under certain other circumstances. This can be especially true when land-use and travel patterns have evolved around transit and other services that operate on dedicated rights of way and provide clear travel time or cost benefits over congested highway travel to central areas. The increased use of HOV facilities across the U.S. is also making composite impedances more relevant.

If composite impedances are to be incorporated, it is important that the simple or weighted average is **not** used for their calculations. When the simple or weighted average is used, the introduction of a new travel mode option between an origin and destination can inappropriately increase the composite impedance. According to Ortuzar and Willumsen (1990, page 165), the composite costs at worst should remain the same when a new option for travel is added. Using averages causes additional inconsistencies, especially when modes such as transit have different geographic service areas.

The impact of each mode on the impedance should be a function of the likelihood that mode will enter into the origin-destination decision of a particular zone pair. If transit service is not likely to be used by travelers between two zones, it should have relatively little influence on the impedance between the zones.

The most common form of composite impedance currently in application is the logsum of the utility functions found in the mode choice models for the area or:

$$\textit{Composite Impedance} = \ln(\Sigma A_i)$$

Where:

A_i = *mode choice disutility function for mode i*

Another form that has been used is the harmonic mean formulation. The harmonic mean is calculated as:

$$\text{Composite Impedance} = \frac{1}{\Sigma(\frac{1}{A_i})}$$

Where:

A_i *= mode choice utility function for mode i*

Both of these formulations have the desired attributes for composite impedance (PBQD, 1992). The log sum approach has the added benefit that it has been incorporated into extensions of the Evans Procedure in combined models of travel choice by Boyce (1995), Metaxatos (1995), and others.

> Recommendation: Proceed with composite impedance inclusion carefully, and only where it is necessary due to high transit or HOV use and/or large travel time or cost savings of the non-SOV modes over SOV modes.

5.8 Hyper-Sensitivity

> Issue: Feedback, especially when it is incorporated at many levels has the potential to make the results more sensitive for short-term forecasting than is appropriate.

The feedback mechanisms incorporated into the travel forecasting models presume that all decisions are made based on the differences in travel times and costs. They also assume that the travel sensitivities captured in the trip distribution model friction factors remain relatively constant over time.

As congestion is incorporated into the feedback loop, the zone-to-zone interactions and relationships will change, possibly drastically, under future congestion. This Again, this has the potential to produce unreasonable shifts in travel patterns.

> Recommendation: In forecasts with feedback, it is important that the resultant change in trip tables from current conditions be monitored and checked for reasonableness.

5.9 Averaging

Issue: Direct feedback of travel times without averaging can result in unstable model performance.

Direct feedback processes that feed the times from the assignment directly into a new execution of trip distribution or other steps should not be implemented. Direct feedback methods tend to be more unstable, producing oscillations, taking longer to converge, and perhaps not converging at all. The Methods of Optimal Weighing for assignment-distribution feedback and extensions incorporating mode choice calculate a weighted average of the current iteration and previous solutions to produce a new overall solution. They are similar to the methods used by the Frank-Wolfe Algorithm in equilibrium assignment. They have also been shown to converge (See Chapter 3). The Methods of Successive Averages can be taken as a simplification of these approaches and have also been shown to converge though possibly at a slower rate under some conditions.

Recommendation: It is recommended that an averaging method be used when implementing feedback for travel forecasting.

References

Baltimore Metropolitan Council Of Governments (BMC), "Validation Of Baltimore Regional Travel Demand Model," Baltimore Maryland, 1992.

Boyce, D. E., Day, N. D., and McDonald, C., Metropolitan Plan Making: an Analysis of Experience with the Preparation and Evaluation Of Alternative Land Use And Transportation Plans, Regional Science Research Institute, Philadelphia, Pennsylvania, 1970.

Boyce, D.E., Zhang, Y.F., Lupa, M.R, "Introducing Feedback into Four-Step Travel Forecasting Procedure Versus Equilibrium Solution of Combined Model," Transportation Research Record # 1443, Transportation Research Board, Washington D.C. 1994. pp 65-74.

Boyce, D.E., Unpublished Correspondence to COMSIS Corporation, April 24, 1995.

Boyce, D.E., LeBlanc, L.J., Chon, K.S. "Network Equilibrium Models of Urban Location and Travel Choices: A Retrospective Survey," Journal of Regional Science, Volume 28, No. 2, 1988.

Denver Regional Council Of Governments (DRCOG), "Travel Models For Regional And Subregional Planning In The Denver Region," Denver Colorado, 1992.

Euler, G. W., Robertson, H.D., National ITS Program Plan: Volume I, U.S. Department of Transportation, Joint Program Office For Intelligent Transportation Systems, Washington, D.C., March 1995.

Evans, S.P. "Derivation And Analysis Of Some Models For Combining Trip Distribution and Assignment," Transportation Research, Vol 10. pp 37-57, Pergamon Press, 1976

Federal Highway Administration (FHWA), U.S. Department of Transportation, "Documentation of Feedback Procedure," Unpublished Research Memo from Lisa Gion to Chris Fleet and Brian Gardner, September 8, 1994.

Florian, M., EMME/2 User's Manual: Software Release 5.0, Inro Consultants, Montreal, Canada, 1991.

Florian, M., Nguyen, S., “A Method for Computing Network Equilibrium with Elastic Demands,” Transportation Science, pp. 321-332, 1975.

Florian, M., Nguyen, S., Ferland, J. "On The Combined Distribution-Assignment of Traffic," Transportation Science, Vol. 9, pp 43-53. 1975.

Harvey, G. and Deakin, E., A Manual for Transportation-Air Quality Modeling for Metropolitan Planning Organizations, National Association of Regional Councils, Washington, D.C., November 20, 1993.

Horowitz, A.J., "Convergence Of Certain Traffic And Land-Use Equilibrium Assignment Models," Environment and Planning, Volume 23. pp 371-383, 1991.

JHK & Associates and COMSIS Corporation, IVHS Benefits Assessment Modal Framework - Final Report, prepared for the Volpe National Transportation Systems Center, U.S. Department of transportation, Cambridge, MA, July 1994.

Lawton, T.K., Walker, R.E. "Transportation Model Equilibrium - In Practice It's Simple," Paper Presented at the Fourth National Conference of Transportation Planning Methods Applications, Daytona Beach, Florida, April 1993.

Levinson, D.M., Kumar, A., "Integrating Feedback into the Transportation Planning Model: Structure and Application," 72nd Annual Transportation Research Board Meeting, Washington, D.C., January 1993.

Mann, W. "Travel Demand Forecasting Process Used By Ten Large Metropolitan Planning Organizations, Institute Of Transportation Engineers, 1993.

Metaxatos, P., Boyce, D., Florian, M. and Constantin, I., "Introducing 'Feedback' Between the Origin-Destination, Mode, and Route Choice Steps of the Urban Travel Forecasting Procedure in the EMME/2 System," Proceedings, 5th TRB Transportation Planning Methods Applications Conference, Seattle, WA, 1995.

Metropolitan Washington Council Of Governments (MWCOG), FY-94 Development Program For MWCOG Travel Forecasting Models, Volume A: Current Applications, Washington, D.C. 1994.

Morrison, J. and Loose, V., Urban Transportation Networks: Equilibrium Analysis With Mathematical Programming Methods, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1985.

Ortuzar, J.D., Willumsen, L.G., Modeling Transport, John Wiley & Sons, Chichester, England, 1990.

Parsons, Brinckerhoff, Quade & Douglas, Inc. (PBQD), Review Of Best Practices , Prepared for the Metropolitan Washington Council Of Governments, Washington, D.C., December 1992.

Sheffi, Yosef, Urban Transportation Networks: Equilibrium Analysis With Mathematical Programming Methods, Englewood Cliffs, New Jersey, Prentice-Hall,
Inc., 1985.

United States Congress, Clean Air Act Amendments of 1990.

United States Environmental Protection Agency, "Section 187: VMT Forecasting and Tracking Guidance," January 1992.

United States Environmental Protection Agency. "Criteria and Procedures for Determining Conformity to State or Federal Implementation Plans of Transportation Plans, Programs, and Projects Funded or Approved Under Title 23 U.S.C. or the Federal Transit Act: Final Rule," November 1993.

U.S. Environmental Protection Agency, User's Guide To Mobile 5a (Mobile Source Emission Factor Model). Report No. Epa-AA-TEB-91-01, Emission Control Technology Division, Test and Evaluation Branch, Ann Arbor, Michigan, 1994.

U.S. District Court for Northern California. "Sierra Club v. Metropolitan Transportation Commission, et al.," Civil No. C-89-2064-TEH, and "Citizens for a Better Environment et al. v. Peter B. Wilson et at.," Civil No. C-89-2044-TEH, 1990.

Van Vuren, T., Unpublished Correspondence From the Hague Consulting Group to Larry Seiders, COMSIS Corp., May 30, 1995.

Walker, W.T., Peng, H. "Alternate Methods to Iterate A Regional Travel Simulation Model: Computational Practicality An Accuracy." Paper Presented at the 74th Annual Meeting of the Transportation Research Board, Washington, D.C., January 1995.

Appendix A REGULATORY REQUIREMENTS FOR FEEDBACK

A.1 Introduction

The 1990 Clean Air Act Amendments (CAAA) have placed new emphasis on the outputs of transportation forecasting processes and their sensitivity to travel reduction or congestion reduction strategies. This in turn has focused attention on "feedback" in the traditional four-step travel forecasting process to ensure that the methods properly account for the congestion that does exist and its impact on travel and location decisions. Feedback has been explored as a means to ensure that:

- the speeds and travel times used as inputs to trip distribution and other travel decisions (land-use location, trip generation, mode choice, time-of-travel, etc.) are the same as those produced by the final assignments, and

- the speeds and travel times produced by the process for input into air quality and other analyses reasonably reflect the speeds and travel times that actually exist under the forecasted or modeled scenario.

This chapter focuses on the arguments for introducing feedback in the traditional four-step travel forecasting processes and the requirements of the 1990 CAAA for doing so.

A.2 Feedback and the 1990 Clean Air Act Amendments

A.2.1 Emission Inventory Preparation

The 1990 CAAA required the development of "comprehensive, accurate, and current" inventories of each pollutant (for mobile sources this includes NOx, and volatile organic compounds or the pre-cursors to ozone, carbon monoxide, and small particulates, PM_{10}) for every nonattainment area (marginal and worse) as part of the CAAA State Implementation Plan (SIP). The required emissions inventories were due by November 1992 and must be updated every three years thereafter. The inventories are used to establish the emissions baseline from which conformity to the CAAA is gauged, the relative share of mobile and stationary sources, the resulting emission reduction budgets, and in determining reasonable further progress and attainment.

The U.S. Environmental Protection Agency's guidance on the preparation of emissions inventories (U.S. EPA, 1992) provides two methods for developing the inputs to the emissions inventory for highway vehicles: factoring from the federally mandated Highway Performance Monitoring System (HPMS) and the use of travel demand network models adjusted to match the HPMS totals. The inventory guidance describes feedback as a necessary part of the travel forecasting process and in fact footnotes that the U. S. District Court of Northern California ruled that "where the model had the capability to incorporate feedback effects the planning agency was obliged to project travel with those effects included" (U.S.EPA, 1992, page 87). It also emphasizes that:

> EPA considers that the feedback effect between trip assignment and the trip origin/destination is the most important at this time, given the current state of modeling practice and the potential for model improvement that incorporating such effects may have. The link travel times used for trip distribution should be consistent with the results of the trip assignment step. (U.S.EPA, 1992, page 87).

While the EPA does not state when the network model approach should be used, it does suggest that the network model provides valuable information as to where and when travel may occur in the region. When network models are used, however, the above feedback discussion does apply.

A.2.2 <u>VMT Forecasting and Tracking</u>

Moderate and/or serious carbon monoxide (CO) nonattainment areas must forecast vehicle miles traveled (VMT) on an annual basis up to the prescribed date for their attainment. VMT estimates and forecasts are also needed for conformity analysis and the emissions inventories. The "Section 187 VMT Forecasting and Tracking Guidance" (U.S.EPA, January 1992) , like the emissions inventory procedures, provides two methods for developing the VMT estimates: factoring from the HPMS, or a network-based travel forecasting process adjusted to match the HPMS totals. The VMT guidance is much stronger, however, in its recommendations for the use of the network models:

> For forecasting VMT, network models were chosen as the best method. Though these models are not considered to be a superior source of historical area-wide VMT, if they are well validated and if they use an **equilibrium approach** to allocating trips, they are considered to be the best predictor of growth factors for VMT forecasts. (U.S.EPA, Jan. 1992).

Serious CO nonattainment areas must use a network based model to forecast the growth in VMT to the year 2000. Moderate CO areas are not required to use a network model since their attainment date is much sooner (January 1, 1996); however, it is recommended that they do so.

When network-based models are used for the VMT forecasts they must be documented in the State Implementation Plan (SIP) and all subsequent changes also documented in the required annual reports. A number of feedback features must be documented in the SIP, including the following:

- that the travel demand forecasting model method uses a constrained equilibrium approach to allocating trips among links,

- that a distinction is made between peak versus off-peak trip volumes and travel times,

- that model outputs on zone-to-zone travel times are recycled as inputs until a self-consistent equilibrium trip assignment among zones is achieved and that this recycling is done until a self-consistent equilibrium trip assignment is achieved among modes as well, if transit trips make up a significant portion of historical or expected future travel on the network,

- that no link is loaded beyond its reasonable capacity, and

- that the travel demand forecasting model forecasts of future year VMT are based upon the future demographic and land-use assumptions of the agency responsible for making such forecasts for transportation planning purposes and upon the future highway and transit network, and that the demographic land-use assumptions for future years are reasonable in light of the planned highway and transit network, local land-use policy, and other relevant influences on public and private development and location decisions (U.S. EPA, Jan. 1992).

The VMT tracking guidance calls for feedback to be performed with respect to assignment, trip distribution, and mode split. It again recommends that the land use and transportation scenarios be consistent but does not require formal feedback.

A.2.3 <u>Conformity</u>

Each regional and state Transportation Improvement Program (TIP and STIP), Transportation Plan, and projects of regional significance requiring a Major Investment Study must be shown to be in conformity with the approved CAAA SIP. The "Criteria and Procedures for Determining Conformity to State or Federal Implementation Plans of Transportation Plans, Programs, and Projects Funded or Approved Under Title 23 U.S.C. or the Federal Transit Act: Final Rule" which determines the analytic requirements for conformity was released in November 1993 by the Environmental Protection Agency. It is one of the few federal regulations that directly calls for feedback to be used in transportation forecasting.

All conformity analyses are based upon the EPA/DOT prescribed criteria. They must have the following characteristics:

- be based upon the region's latest planning assumptions and forecasts,
- be based upon the latest EPA-approved emissions models,
- be based on consultation with air quality agencies,
- provide for timely implementation of TCMs,
- demonstrate consistency with emissions budgets in the SIP,
- be based on regional emissions analysis in nonattainment and maintenance areas,
- eliminate or reduce CO hotspots in CO nonattainment areas,
- does not create CO hotspots,
- contributes to reductions of ozone and CO emissions in ozone and CO nonattainment areas, and
- contributes to reductions or not increase PM_{10} or NO_2 directly in PM_{10} and NO_2 nonattainment areas, (Morrison, J., Loose, V., 1994).

For serious, severe, and extreme ozone nonattainment areas and serious carbon monoxide areas the procedures for determining regional transportation-related emissions must be determined from a "network-based transportation demand model or models relating travel demand and transportation system performance to transportation infrastructure, and transportation policies" (U.S. EPA, November 1993). These network-based models "must have" or are "strongly encouraged" to have a number of feedback mechanisms built into their structure. They must have:

- a capacity-sensitive assignment methodology for peak-hour or peak-period traffic assignments (*assignment feedback*),

- methods to estimate traffic speeds and delays that are sensitive to traffic volumes in the network model,

- zone-to-zone travel times used to distribute trips between origin and destination pairs that are in reasonable agreement with the travel times that result from the process of assignment of trips to network links (*assignment to trip distribution feedback*),

- where use of transit is significant, final zone-to-zone travel times consistent with those used for mode choice (*assignment to mode choice feedback*) ,

- peak and off-peak travel demand and travel times (*time-of-day sensitivity*), and

- a logical correspondence between the assumed land use scenario and the future transportation system.

After January 1, 1995, conformity analyses in severe and worse nonattainment areas must come from network-based travel forecasting models that have assignment and trip distribution feedback and provide time-of-day estimates of demand and travel times. If transit use is significant the transit mode-shares must also be consistent with the final assigned travel times. The base horizon year transportation networks and land use scenario must also be shown to be consistent. Additional requirements are also provided including base year validation, inclusion of pricing in trip distribution, and the estimation of free-flow speeds that are not related to feedback but are important aspects of the model system.

The EPA strongly encourages that the models have the following:

- a dependence of trip generation on the accessibility of destinations via the transportation system (*trip generation to network connectivity and assignment*),
- a dependence of regional economic and population growth on the accessibility of destinations (*land use to network connectivity and assignment*), and
- the use of formal land use models.

The direct treatment of the impact of the transportation system and congestion on the number of trips made (trip generation), the land use/transportation interaction, and overall growth is recommended but not absolutely required in these severe and worse nonattainment areas.

An analysis of carbon monoxide (CO) intersection/local hotspots is also called for in project conformity and in areas of CO nonattainment. Feedback is not directly required for these evaluations but may be necessary to produce valid estimates and forecasts of the inputs to the air quality emissions model used to assess hotspots. The recommended approach for overall analysis of CO hotspots requires first ranking the 20 worst intersections in the area by their traffic volumes and level-of-service (LOS is based on seconds of delay per vehicle. LOS F occurs when delay per vehicle is greater than 60 seconds). Since feedback and equilibrium assignment can have a marked effect on the location of congestion in a region, it may be important to include a feedback process in this assessment. After the intersections are ranked, the three worst must be modeled for CO. Intersection analysis requires accurate reporting of the worst hour volumes and vehicle speeds on each leg of the intersection. Again, while not required directly, feedback to trip distribution, mode choice, and time-of-day may be needed to correctly capture these values for future years.

Areas that are in attainment or below the severe category in nonattainment are not directly required to implement a network-based model with these features. It may be advantageous to implement a network-based model in any case, however, to assist in the analysis of TCMs and air quality emissions assessment. If a network-based model does exist it may also be highly desirable to implement the required feedback mechanisms discussed above.

A.2.4 Speed and Travel Time

The recent EPA guidance supporting the Clean Air Act Amendment of 1990 has provided the necessary motivation for modelers in most non-attainment areas to pursue the options for feedback despite the additional time and resource requirements, and the potential pitfalls of inappropriate application of the procedures. Further motivation is also provided by the ever-increasing need for sensitivity to travel time changes that result from regional growth or from improvements to the transportation system. A significant relationship between the rate of pollutant emissions and the speed at which the vehicle has been traveling has long been established (U.S. EPA., 1994). Any improvement to the modeling system that will produce more accurate forecasts of final speed will aid in planning for a reduction in pollutant emissions through transportation programs. In addition, there is a growing interest in management strategies that can achieve greater use of already existing transportation infrastructure for which greater sensitivity to speed differences is necessary if regional models are to be useful planning tools. The U.S. Department of Transportation's initiative for Intelligent Transportation Systems (ITS) funded under the Intermodal Surface Transportation Efficiency Act (ISTEA) has heightened the nation's interest in these management-oriented strategies and has increased the interest in more accurate model systems (Euler and Robertson, 1995). The introduction of feedback mechanisms would appear to be a major step forward in providing additional sensitivity and accuracy in the evaluation of management strategies.

NOTICE

DOT-T-96-14

DOT-T-96-14

Technology Sharing

A Program of the U.S. Department of Transportation