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Improvements to Mobility Performance Measure Calculations

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Cambridge Systematics, Inc.

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16. Abstract

Since the early 1900s the Colorado Department of Transportation (CDOT) has undertaken many activities to advance the use of system performance measures to help make informed investment decisions related to transportation in Colorado. Through the years the activities have evolved into a system of customer-orientated, outcome-based performance measures for Mobility, Safety, System Quality (Maintenance & Preservation - Surface Condition & Bridge), and Effectiveness (Administration & Operations). The practice has evolved to the point where the department is ready to prepare initial performance measures for the various component areas and present the measures to the Transportation Commission for consideration.

Throughout the performance measure development process, data and methodologies have been employed for the purpose of advancing the concept, but that knowingly fell short of acceptable data quality and reliability standards. In preparation for reporting the mobility performance measures CDOT seeks recommendations for both short- (year 2000) and long - term (post year 2000) improvements to calculating and reporting various mobility performance measures. This current report presents research findings and recommendations for improving several mobility performances measure data collection sonrces and measurement estimation techniques. Major sections of the report address criteria to report statewide congestion, required enhancements to the existing CDOT travel data collection and analysis system, short-term improvements, and long-term improvements.

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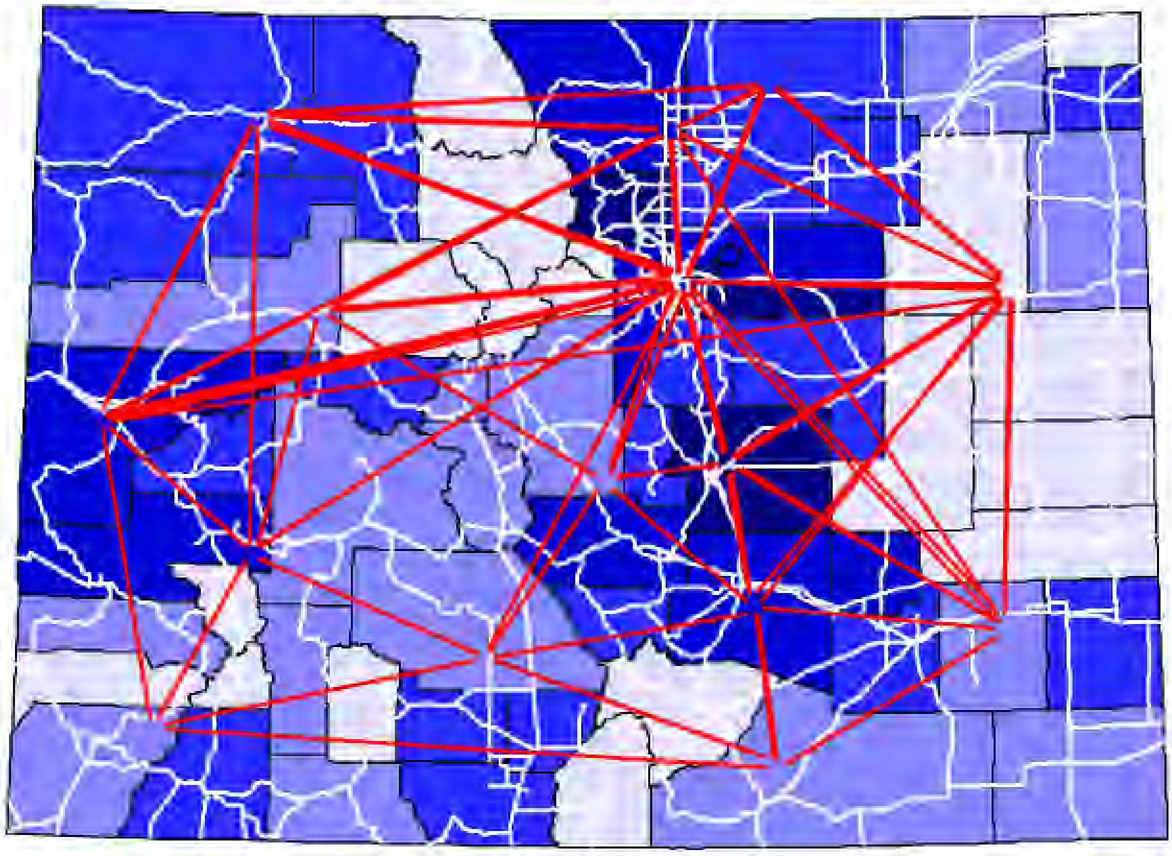
CDOT Travel Database Improvement Project

Improvements to Mobility Performance Measure Calculations

Final Report



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EXECUTIVE SUMMARY

INTRODUCTION AND BACKGROUND

This report is designed to address short- (year 2000) and long-term (post year 2000) improvements to calculating and reporting mobility performance measures. The short-term recommendations are made from careful analysis of available data, knowledge of existing methods and practices, and consideration for time constraints in developing adequate year 2000 estimates of congested person miles traveled (CPMT) and congested freight ton-miles traveled (CFTMT). Long-term recommendations flow from investigation of existing methods and technologies employed around the country and from research of alternative methods published in popular research journals.

The report is organized into five sections. Section I provides an introduction to the report and background on CDOT's efforts to develop a performance measurement system. Section II addresses criteria to report statewide congestion. Section III presents required enhancements to existing CDOT travel data collection and analysis. Section IV outlines existing methodologies employed by CDOT in measuring mobility performance and recommends short-term improvements to be used in preparing the year 2000 mobility performance measures. Finally, Section V presents recommended long-term improvements to measuring and reporting mobility performance measures.

CDOT INVESTMENT STRATEGY FRAMEWORK

Mobility performance measurement began in support of an overall CDOT investment strategy component of the *Intermodal Management System (IMS)* demonstration project in the mid-nineties. During this same period, performance measurements related to infrastructure preservation were developed as part of the *Pavement Management System (PMS)*. Additional measures were developed as part of the *Congestion Management System (CMS).* Shortly after the IMS project concluded, CDOT funded the *Strategic Corridor Investment Program* to develop a system for prioritizing and programming corridor improvements eligible for accelerated funding due to statewide significance. Measures based on mobility, safety, and system preservation were developed for many corridors around the state to determine the highest priority needs statewide.

Following the *Strategic Corridor Investment Program* CDOT developed the *Near-term Investment Program*. The purpose of the *Near-term Investment Program* was to develop a customer-oriented, outcome-based, performance measurement system designed to optimize CDOT's investment program among the four primary investment categories of Safety, System Quality (Maintenance & Preservation – Surface Conditions & Bridge), Mobility, and Effectiveness (Administration & Operations). The performance measures identified in the final report provided a tool for forecasting outcomes of alternative investment strategies during the program commitment phase of the program cycle and were also designed to monitor trends, or outcomes, from implemented investment program packages.

In an effort to further develop the performance measurement program, CDOT conducted the *Transportation Investment Strategy* project. This project, completed in 1999, re-examined and revised the previous mobility performance measures by adding a structure of goals to be achieved through the mobility component of the overall transportation investment program. Also, the *Transportation Investment Strategy* project categorized the mobility goals and measures by program level and investment level. Investment level measures were developed for use by senior management and the Transportation

Commission in tracking overall performance within each Investment Category. The Program level performance measures provide details to support the investment level measures and are proposed for use by senior management for reviewing programs in the context of the overall Investment Category.

Each of these earlier efforts served to advance the investment strategy framework and the concept of using performance measures to help develop investment programs. Accuracy of the data elements was secondary to promoting the overall program. Measures were developed and estimated to conceptually demonstrate the advantages of performance-based programming. Now that the concept has achieved a relatively high level of interest, if not acceptance, among CDOT's senior leaders, it is appropriate to expend resources in developing new procedures to more accurately reflect the true performance of the system.

CRITERIA TO REPORT STATEWIDE CONGESTION

The desire to develop criteria to report statewide congestion relates to the procedures, thresholds, and other elements involved in reporting mobility performance measures. Specifically, CDOT is interested in:

- How to best compare congestion measures between urban and rural highways (Urban and Rural Highways).
- Determining the criteria for reporting congested person miles traveled, congested freight ton-miles traveled, and number of congested hours per year (Congestion Measure Reporting Criteria).
- Determining a conceptual approach to combining volume and speed data at automated traffic recorders (ATRs) to identify congestion when high traffic density and low speeds are present.

With regards to reporting criteria for urban and rural highways CDOT is interested in whether different thresholds are appropriate for the two components of the highway system. To accomplish this several states were surveyed to identify peer practices. Through the investigation the states of Arizona, California, Florida, Idaho, Minnesota, New Mexico, Texas, and Washington were surveyed. In addition, two national systems were examined for differences in urban and rural system performance thresholds: HPMS, and the Highway Economics Requirements System.

The investigation found that:

- Most states/methods at least differentiate urban and rural congestion measures.
- Many states/methods have more than two levels of differentiation.
- Some states do not track congestion, to the same degree or at all, outside urban areas.
- Most states consider congestion as one among many other measures (safety/accidents, road condition) when making investment decisions.
- Volume to capacity (V/C) ratio and level-of-service (LOS) are the most common congestion threshold measures.
- Few states reference duration (LOS and V/C imply peak hour).

Recommendations include:

- Focus mobility performance measurement efforts on a select list of significant mobility corridors. Others add little value to CDOT for investment decision-making.
- Continue to use 0.85 V/C as the congestion threshold until a study of acceptable congestion levels in urban and rural areas can be conducted.

- Focus mobility performance measurement efforts on CDOT facilities. The CDOT Transportation Commission (TC) does not make investment decisions on non-CDOT roadways. These decisions are made at a local level and projects requiring federal funds pass through the Statewide Transportation Improvement Program (STIP) process for review and are screened for consistency with statewide objectives.
- Report mobility performance measures in terms of average weekday, average weekend day, and annual total hours and miles traveled under congested conditions.

REQUIRED ENHANCEMENTS TO EXISTING CDOT TRAVEL DATA COLLECTION AND ANALYSIS SYSTEM

This report is focused on short- and long-term improvements to mobility data collection, analysis, and reporting systems. Throughout the report are specific recommendations to improve the mobility performance measurement process. Some of these recommendations relate more to improving data quality for specific measures and have little influence on the overall system. The following recommendations are included elsewhere in the report, but are presented here because of their broad application to multiple mobility performance measures and the overall investment strategy effort at CDOT. These are considered to be “required enhancements” to the system as opposed to improved methodologies.

- Define a mobility subset of the overall state highway system for purposes of mobility performance measurement. This will serve to reduce data quality conflicts and conserve data collection and analysis resources for those corridors most likely to benefit from near-term mobility investments.
- Re-design the seasonal ATR groups for Colorado and take steps to expand the number of ATR locations to better distribute the facilities across all components of the state system.

Of all the recommendations identified by topic area in this report these appear to have the widest span of impact on the state and the overall performance-based customer-oriented investment strategy.

SHORT-TERM IMPROVEMENTS

Average Vehicle Occupancy Short-term Improvements

Average vehicle occupancy (AVO) is an estimate of the mean number of people carried by any given passenger vehicle – or the number of persons per vehicle. In previous mobility performance measure development work, CDOT utilized aggregate vehicle occupancy estimates for each county. These estimates were generated from statewide accident records supplied by the Department of Revenue, Division of Motor Vehicles (DMV). The DMV annually assembles the information entered on all accident records in the state and archives this information onto computer tape, which is then distributed to interested agencies such as CDOT. Using the information from the accident records, CDOT has been able to estimate the number of passengers per vehicle. Past mobility performance measurement efforts aggregated the information at the county level for all periods of the day.

While past approaches were expedient and met the minimum data needs to help the performance measurement work progress, data aggregated at the county level for all time periods throughout the year may not accurately represent vehicle occupancy during peak, or congested, periods of the day.

Additionally, this macro level aggregation does not discriminate between roadway facility types (e.g., interstate, rural other, principal arterial, etc.).

The methods available to estimate average vehicle occupancy are generally by survey (e.g., observing occupancy rates through roadway surveys, a phone/mail travel diary survey, etc.) or through estimation methods using other available data sources. Due to time and other constraints, it is not feasible to conduct a statewide survey of vehicle occupancy in support of the year 2000 mobility performance measure reporting. Thus, it is recommended that CDOT pursue generating revised vehicle occupancy estimates using the accident data as before. Using the accident data, it is further recommended that CDOT use multiple years (to increase the sample size) and segregate the data by time of day and either facility type or specific corridor.

Average Truck Weight Short-term Improvements

Average net cargo weight per truck is a component of the Congested Freight Ton-Miles Traveled (CFTMT). It is applied for two categories of composite trucks maintained in the CDOT traffic databases, single-unit trucks and combination trucks. The current values for net cargo weight per truck were provided by CDOT's Commercial Vehicle Operations office as part of the previous two mobility performance measurement studies. The values are based on samples from the Colorado Department of Revenue's Ports of Entry (POE) that estimate the average weight for single-unit and combination trucks as approximately 26,500 pounds and 61,800 pounds respectively. The study further reportedly suggested that 45.5% of a truck's weight is attributed to freight.

For the year 2000 it is recommended that for the average cargo weight per truck type estimate, CDOT use data from existing weigh-in-motion (WIM) sites. It is believed that these data will better represent the actual distribution of truck weights on the road since POE data are biased towards loaded trucks. Furthermore, the rural POE data primarily captures combination trucks whereas the congested roadways that are of most interest have a predominance of single-unit trucks since they are mostly located in urban areas.

It is further recommended that the level of reporting of CFTMT be at a summary level for the year 2000 report because the data are generally not available to confidently report this measure at finer levels. Summary levels include a statewide single value by truck category and statewide by truck category by functional classification of roadway. The data sources that are available and that can be analyzed for this reporting period will generally only provide statewide values for average gross and cargo weight per truck type. Furthermore, the vehicle classification data that are also necessary to support computation of the CFTMT measure are not yet confidently available on a corridor-specific basis.

Vehicle Classification Short-term Improvements

Vehicle classification data are used to estimate the number of trucks by type on each roadway segment so that average cargo weight values can be applied for the computation of Congested Freight Ton-Miles Traveled. Two composite truck types are used – single-unit trucks and combination vehicles as described in the previous section. The current method of estimating vehicle classification is via CDOT's permanent classifier and weigh-in-motion sites and manual classification counts. Very few roadway segments are directly observed as compared to volume counts. Furthermore, most of the data are available for rural roadways rather than the congested urban roadways that are the focus of this measurement effort.

No major changes or new data efforts are recommended for the year 2000 reporting of CFTMT. This is because any improvements in vehicle classification would involve new data collection and analysis schemes that are not feasible within the time frame available. However, a CDOT effort that is currently underway to test and evaluate a "cluster" counting methodology for vehicle classification will provide some limited direct observations that can be incorporated into the computations for the year 2000 reporting. It is recommended that CDOT maintain existing methodology for estimating vehicle classification in the short term, although a limited amount of new data may be available from a test of the cluster sampling technique currently under way.

Annual Average Daily Traffic, Percent Trucks, Directional Distribution, and Highest Hourly Volume Short-term Improvements

Annual average daily traffic (AADT), directional distribution (DD), and highest hourly volume data elements are all estimated or measured from data collected by automatic traffic recorders (ATR) from across the state. Currently there are approximately 72 functioning ATRs on state highways in Colorado. ATRs collect traffic data 24 hours a day, 365 days a year (except when down for maintenance). Based generally on procedures outlined by FHWA in the *Traffic Monitoring Guide*, CDOT aggregates these 72 ATRs into 7 "seasonal" groups to develop profiles (or snapshots) of traffic characteristics.

Temporary 24- and 48-hour hose counts are taken during the summer on roadway segments across the state that lack ATR sites. The temporary counts are taken on a three-year rotational basis. Profiles from the temporary counts are then compared to profiles for the seasonal groups to identify proper assignment of the temporary count roadways to the seasonal groups. Professional judgment is used to assign roadway segments to seasonal groups where no ATR or temporary counts exist. With the use of the seasonal group profiles CDOT is able to estimate AADT, directional distribution, and highest hourly volume for all state highway segments. The methodology for estimating percent trucks is described under the vehicle classification section of this report.

Of concern here is how well these profiles, as currently developed, accurately predict congestion levels across the state. As stated, the procedures used by CDOT are generally based on those prescribed by the *Traffic Monitoring Guide*. These were developed by FHWA to support reporting requirements of the Highway Performance Monitoring System (HPMS) and are standard practice across the country. With regards to the purpose for which they were developed, the procedures paint an acceptable picture of aggregate traffic conditions. However, they may not be appropriate for adequate representation of congested conditions, especially on weekends and across multiple hours of the day, in the state.

It is recommended that new procedures be applied for grouping the ATRs and for estimating AADT, directional distribution and highest hourly volume. Specifically, it is recommended that seasonal weekday and weekend factors, along with hourly profiles, be developed by each new ATR group to more accurately reflect traffic behavior across all periods of the day and weekday/weekend components of the week and that the temporary count program be adjusted to provide for seasonal short term counts. However, time does not exist to develop these profiles and ATR groups for year 2000 reporting; therefore, it is recommended that these be developed for the next reporting cycle.

LONG-TERM IMPROVEMENTS

Average Vehicle Occupancy Long-term Improvements

The methods available to estimate average vehicle occupancy is generally by survey (e.g., observing occupancy rates through roadway surveys, a phone/mail travel diary survey, etc.) or through estimation methods using other available data sources. Due to time and other constraints, it is not feasible to conduct a statewide survey of vehicle occupancy in support of the year 2000 mobility performance measure reporting. However, it is recommended that CDOT pursue generating revised vehicle occupancy estimates using a combination of roadside observations and a predictive model developed for using accident data to estimate AVO.

Average Truck Weight Long-term Improvements

Long-term recommendations for statewide average truck weight are to not go beyond any of the short-term improvements, as the value added to the CFTMT measure by a more accurate average truck weight value does not appear to be commensurate with the level of effort necessary to obtain it. Furthermore, available resources would provide a better return by improving the vehicle classification aspect of the program rather than the average truck weight component.

Vehicle Classification Long-term Improvements

Long-term recommendations for vehicle classification include expansion of the manual cluster count technique and use of data acquisition capabilities from the CDOT ITS two-loop speed-density installations to provide length-based vehicle classification.

Most Effective Temporary Data Collection Strategy

In support of the recommendation to report mobility performance measures on specified mobility corridors it is further recommended that CDOT examine the potential for increasing temporary data collection efforts on the associated corridors. With respect to statewide temporary data collection CDOT should continue to pursue the recommendations outlined in the *Traffic Monitoring Strategic Plan* developed for CDOT in approximately 1996. In addition, CDOT should continue to pursue the implementation of additional ATR locations and increasing the budget for ATR maintenance activities. With respect to temporary count practices, it is further recommended that CDOT extend all rural temporary counts to at least 48 hours and add additional temporary counts in other seasons to supplement the summer count program. This also will facilitate the more accurate assignment of roadway segments to the added seasonal groups.

Annual Average Daily Traffic, Percent Trucks, Directional Distribution, and Highest Hourly Volume Long-term Improvements

Current methods employed by CDOT in estimating AADT, directional distribution, and highest hourly volume data elements are presented above with the discussion of short-term improvements. In the short term it is recommended that CDOT use existing estimates of these data elements for mobility performance measure reporting. In the long term it is recommended that CDOT pursue developing new ATR seasonal groups, develop weekday and weekend profiles, and collect multi-seasonal temporary counts on weekdays and weekends to more accurately assign roadway segments to the revised seasonal groups.

SECTION I: INTRODUCTION AND BACKGROUND

CDOT INVESTMENT STRATEGY FRAMEWORK

The development of performance measures is intended to support statewide decision-making at the investment category level by senior managers and the Transportation Commission, as well as help identify system performance at the program level. Some of the data for the statewide mobility performance measures are available at a smaller geographic level, and are "rolled up" into an aggregate statewide number. Because *some* data are available at a smaller geographic level, there is a tendency to want to "unroll" the data and report performance measures at the corridor or segment level. However, many of the data do not currently support reporting of decision-making below the statewide level.

It is first important to understand that each of the mobility performance measures is a composite of many different data components and that not all components can currently be reported with the same accuracy and reliability. Like the old adage, a chain is only as strong as its weakest link; the composite measures can only be reported to the accuracy of the weakest (least accurate) component. For example, CPMT is a composite of the following measures: vehicle miles traveled (VMT) which is calculated from estimates of annual average daily traffic (AADT), volume to capacity ratio (V/C) determined by comparing the 30th highest hourly volume to the estimated roadway capacity, average vehicle occupancy (AVO), and directional distribution (DD). CFTMT is a composite of vehicle classification counts used to compute percent trucks, average weights from weigh-in-motion (WIM) data, proportion of cargo weight to total truck weight, V/C, and DD. Not all data are currently available with enough detail to support decision-making at all levels from statewide to corridor or segment levels.

Second, the CDOT Transportation Commission has expressed a desire to begin tracking these measures during 2000. It is therefore important that both the composite and component measures be reported with accompanying caveats about their respective levels of accuracy and reliability. This should prevent the misuse of data, such as attempting to make a decision at a level that is not supported by the accuracy or reliability level of the reported measure.

Third, beginning with the 2000 reporting of these measures, the importance of the measures will be in establishing a baseline from which trends can be identified. For the measures to become accepted technically and politically, reporting over time must be relatively stable. It is for this reason that an initial set of measures will be reported, and as the component measures are improved, a second parallel set of measures will also be reported. This step-wise or parallel reporting will serve to maintain stable trend lines and to provide a means of transitioning to improved versions of the composite measure in the future. Once a stable trend line has been established for an improved version of the composite measure, the older, less accurate measure can be phased out.

MOBILITY PERFORMANCE MEASURES

The following section presents an outline of the evolution of mobility performance measurement at CDOT. The two primary efforts of relevance to the current work are the *Near-term Investment Strategy* and the *CDOT Transportation Investment Strategy*. Each is summarized below:

Near-term Investment Program

While the foundation for developing system-wide mobility performance measures dates back to the *Intermodal Management System*, the *Congestion Management System*, and the *Strategic Corridor Investment Program*[1], the first introduction of the measures as part of a comprehensive investment strategy was in 1996 as part of the *Near-term Investment Program*[2]. The purpose of the Near Term Investment Program was to develop a customer-oriented, outcome-based system for optimizing the department's investment program among four primary investment categories:

- Safety
- System Quality (Maintenance & Preservation – Surface Conditions & Bridge)
- Mobility
- Effectiveness (Administration & Operations)

This initial program proposed several customer-oriented, performance-based measures within each investment category for use in allocating transportation resources among and between the four investment categories. The investment strategy proposed in the final report involved a continuous cycle of program objective review, program commitment (allocation of resources), program implementation, and program monitoring. The performance measures identified in the report provided a tool for forecasting outcomes of alternative investment strategies during the program commitment phase of the cycle and were also designed to monitor trends, or outcomes, from implemented investment program packages.

With regards to mobility, the *Near-term Investment Program* presented a set of twenty potential mobility performance measures by three primary areas for mobility: Travel Efficiency/Demand Management, Trip Efficiency/Facility Management, and Service Expansion/New Service Delivery. By mobility area, these performance measures were:

Travel Efficiency/Demand Management

- Vehicle Miles Traveled (VMT)
- Person Miles Traveled (PMT)
- PMT / VMT
- VMT / Person
- Truck Vehicle Miles Traveled
- Truck Freight Ton-Miles Traveled
- Truck Freight Ton-Miles Traveled / Truck Vehicle Miles Traveled

Trip Efficiency/Facility Management

- Lost Person Hours
- Lost Freight Hours
- Free-Flow Travel Time / Congested Travel Time
- Average Speed
- Congested Highway Miles
- Congested Highway Miles / Total Highway Miles

[1] In Motion, Inc., *Strategic Corridor Investment Program*, Final Report: 1996.
[2] In Motion, Inc., *Near-term Investment Program*, Final Report: 1997.

Service Expansion/New Service Delivery

- Person Mobility Index
- Freight Mobility Index
- Person Mobility Coefficient
- Freight Mobility Coefficient
- Statewide Mobility Index (as impacted by varying investment levels – all activities)
- Mobility Index (Mobility Program without 7th Pot Projects)
- Regional Mobility Index (with and without 20 Year Plan Elements)

A 1995 baseline, 1990 back-cast, 2000 forecast, and two alternative 2005 forecasts were developed for each measure by the six CDOT transportation regions and the state as a whole. Appendix A, Near-term Investment Program – Mobility Performance Measure Calculations – documents the specific calculations required for the *Near-term Investment Program* mobility measures.

Emphasis in the project was on overall investment program development rather than data quality. The mobility measure calculations were defined by the available data. Several data shortfalls were accepted in the interest of promoting the program. These shortfalls were the same as experienced in the *Transportation Investment Strategy* and today in preparing for the year 2000 mobility performance measure reporting. They include availability of adequate estimates for average vehicle occupancy across the state, problems estimating hours of congestion, identifying an acceptable freight weight for single-unit and combination trucks across the state, and estimating congested highway speeds. The measures themselves were the result of many meetings and coordination efforts among multiple departments in CDOT and are believed to be appropriate in consideration of the advancement of the mobility reporting practice at the time.

CDOT Transportation Investment Strategy

Subsequent to finalizing the *Near-term Investment Program*, CDOT contracted with Cambridge Systematics, Inc. (Cambridge), and BRW, Inc. in a sub-contractor role, in 1998 to continue the investment strategy program. Cambridge and BRW were charged with providing a review of the *Near-term Investment Program*, developing performance goals by investment category, and formulating recommendations for refinement of the associated mobility performance measures. Through this work, Cambridge developed two tiers of investment: Investment Level and Program Level. Investment Level measures were developed for use by senior management and the Transportation Commission in tracking overall performance within each Investment Category.[3] The Program Level performance measures provide details to support the Investment Level measures and are proposed for use by senior management for reviewing programs in the context of the overall Investment Category.

The mobility performance measures were further organized by key measurement area (KMA). KMAs were developed by CDOT as common areas of measurement that are considered across all Investment Categories and Program Areas and are used to evaluate departmental accountability. The resulting mobility performance measures from the *CDOT Investment Strategy* project are identified below by investment and program level (in the final report: *"CDOT Transportation Investment Strategy; Mobility Investment Category,"* October 22, 1999, some of the measures appear in multiple investment levels. Only the first appearance is presented below):

[3] The *CDOT Transportation Investment Strategy* project expanded the number of investment categories to five to include the Strategic Projects (a.k.a. 7th Pot) – 28 high priority statewide projects committed for accelerated funding. In addition, the Effectiveness category was renamed as Program Delivery.

Investment Level

- PMT under congested conditions in Denver, Colorado Springs, and on state highways elsewhere
- FTMT under congested conditions in Denver, Colorado Springs, and on state highways elsewhere
- VHT / capita in Denver, Colorado Springs, and on state highways elsewhere
- Variation in average traffic speed at selected locations
- Congestion severity
- Travel time variability
- PMT / capita in Denver, Colorado Springs, and on state highways elsewhere
- VMT / capita in Denver, Colorado Springs, and on state highways elsewhere

Program Level – Highway Performance

- Average total trip time for selected O-D pairs, by auto and transit in Denver and Colorado Springs
- Tons of mobile source emissions in Denver and Colorado Springs
- Compliance with Colorado Visibility Standards (e.g., # of days of violation/year)

Program Level – Alternative Mode Performance

- Mode split, by trip purpose in Denver and Colorado Springs
- Average vehicle occupancy (AVO)
- Number of park-n-ride lots and spaces, and their utilization
- Percent of auto-less households within ¼ mile of transit
- Availability of travel options

Program Level – Facility Management

- Number of road closures due to weather or incidents and time to reopen

Program Level – Travel Demand Management

- PMT / VMT in Denver, Colorado Springs, and on state highways elsewhere
- Number of days pollution exceeds federal air quality standard

Program Level – Weather Response

- CDOT sand usage

Due to data availability constraints, many of the measures presented above refer to Denver, Colorado Springs, and state highways elsewhere. Denver and Colorado Springs were separated from the rest of the state to take advantage of travel model outputs for calculating many of the measures. In previous efforts, the mobility performance measures were limited to the state highway system and omitted the local transportation system performance. Denver and Colorado Springs MPOs manage regional travel demand models that are capable of calculating traffic conditions on the local networks. Other areas of the state either lack travel demand models in whole or use less sophisticated methods for estimating travel demand on the local system.

Because emphasis was placed on utilizing existing data sources, different thresholds of congestion were used in Denver as compared to Colorado Springs and state highways elsewhere. The Denver Regional Council of Governments (DRCOG) reported percent of VMT under severe congestion, where severe is defined by a volume to capacity ratio (V/C) of 0.95 or higher, and person miles traveled as modeled for the 1996 *Metro Vision 2020 Regional Transportation Plan*. Due to resource constrains on the travel demand forecasting staff at the time, DRCOG was unable to estimate the same measures at the 0.85 V/C congestion threshold used in the other areas of the state. In the future it is recommended that a consistent congestion threshold be used.

Appendix B, CDOT Transportation Investment Strategy Mobility Performance Measure Calculations, presents the methodology employed in calculating each of the investment strategy mobility performance measures.

Findings of Previous Performance Measurement Efforts

The efforts mentioned above served the primary purpose of advancing the investment strategy framework over and above improving the source data required in calculating the mobility performance measures. The success of these efforts in advancing the investment strategy concept is evident in the interest the Transportation Commission has demonstrated in the program. Many of the measures previously calculated relied on surrogate data and "best guess" estimates for the supporting data. Again, the objective of the previous efforts was to demonstrate the capabilities of the system as opposed to obtaining the most accurate data. As the program has evolved, and has been accepted, data reliability has become a more dominant consideration. The following graphic provides a glimpse of the evolution of mobility performance measure data quality along a performance measure continuum.

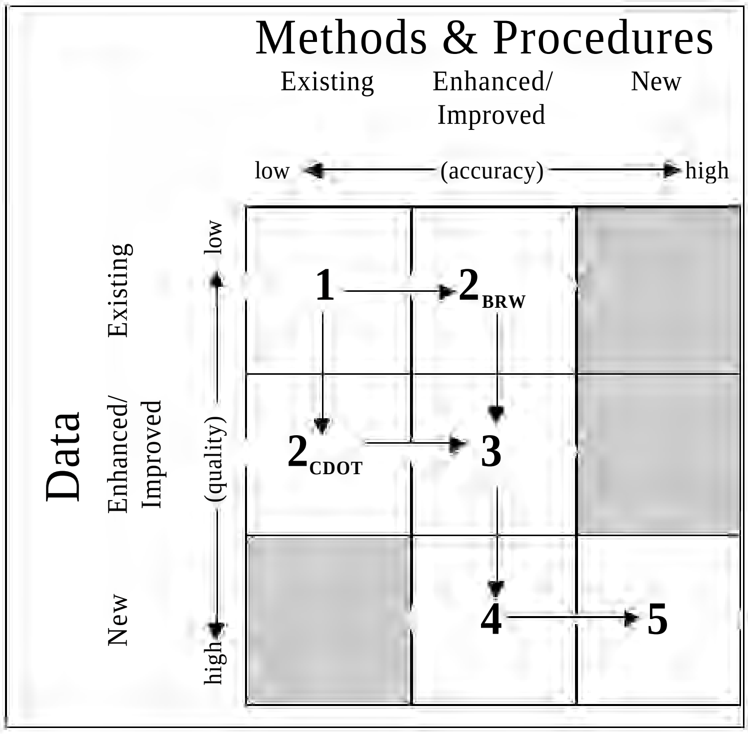
PM Continuum	Confidence Level
Perfect PMs	100%
Long-term (2005+) PMs	X^4%
Year 2001/2002 PMs	X^3%
Year 2000 PMs	X^2%
1999 Investment Strategy Baseline PMs	X^1%
Ground Zero PMs	0%

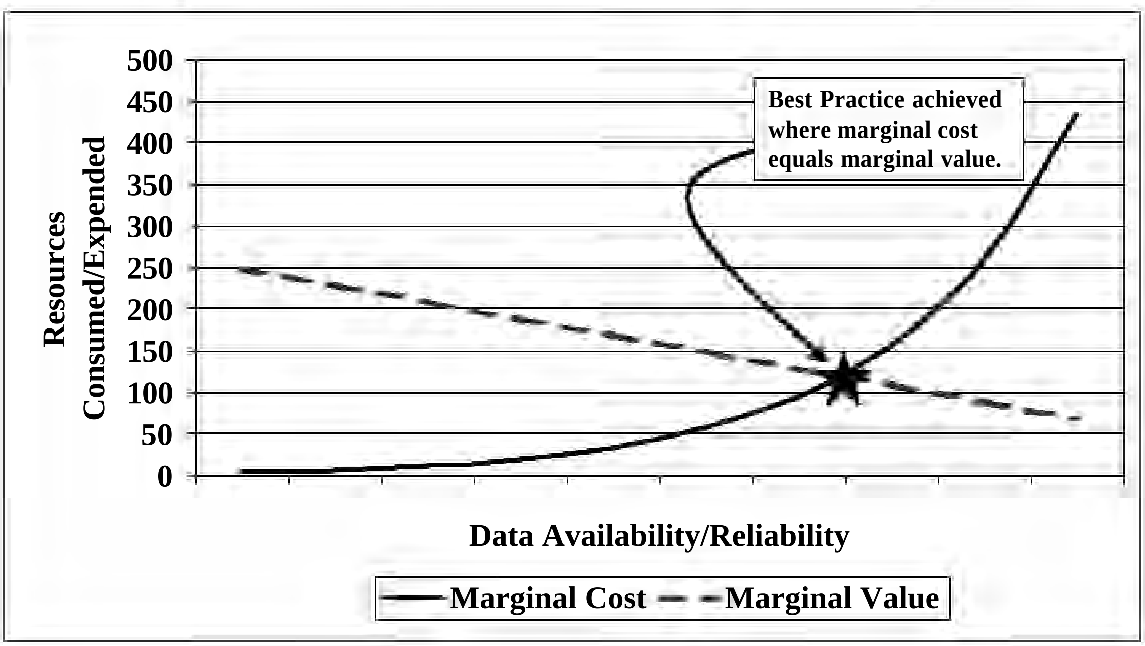
Best Practice is that which maximizes confidence within resource constraints

As illustrated, the confidence level achieved through the measures will increase as the measures and the overall program progress. As more and more emphasis is placed on the program as a decision support tool, the more reliable the underlying data will become, and higher levels of confidence will be realized, while improved measures will be developed. While the "Perfect PMs" with 100% confidence will never likely be achieved, the bar for the "best practice" will continue to rise.

PERFORMANCE MEASURE IMPROVEMENT OPPORTUNITIES

Improving performance measures requires a combination of new data and new analysis methods, both of which must be supported by resources in the form of data collection equipment and staff time. The next figure depicts the relationship between data collection and data analysis, showing current and desired future improvements. In general, the desire is to move from lower accuracy, lower quality outputs to higher accuracy, higher quality outputs. The rates at which the methods and data can be advanced are a function of resource utilization and return on the investment. The second figure depicts this relationship: as the accuracy of data increases, so too does the cost. The "best practice" at any given time is that which maximizes confidence (accuracy/reliability) within resource constraints.





Where:
Marginal Cost = Additional Data Collection Cost / Additional Data Units
Marginal Value = Incremental Increase in Value of Decisions (Change in CDOT Budget) / Marginal Cost of Data Collection

SECTION II: CRITERIA TO REPORT STATEWIDE CONGESTION

Criteria to report statewide congestion relates to the procedures, thresholds, and other elements involved in reporting mobility performance measures. Specifically, CDOT is interested in:

- Determining the criteria for reporting congested person miles traveled, congested freight ton-miles traveled, and number of congested hours per year (Congestion Measure Reporting Criteria).
- How to best compare congestion measures between urban and rural highways (Urban and Rural Highways).
- Determining a conceptual approach to combining volume and speed data at ATRs to identify congestion when high traffic density and low speeds are present (Congestion with High Traffic Density and Low Speeds).

Where data criteria and procedures for calculating the mobility performance measures are presented in the previous sections and in the *Short-term Improvements to Mobility Performance Measure Calculations* report, this section is focused more on the reporting thresholds for the various components. The following discussions present the research and/or analysis and recommendations for each of the areas of interest.

CONGESTION MEASURE REPORTING CRITERIA

Under previous investment strategy efforts mobility performance measures have been reported at the regional and statewide level for state highways only. Most recently under the *CDOT Investment Strategy* baseline mobility performance measures were calculated for all roadways in DRCOG, PPACG, and for state highways elsewhere. Additionally, varying thresholds for volume to capacity have been used to define congestion in these areas.

With regards to congested hours of travel, accepted estimates have only been available for areas with an established regional travel demand-forecasting model capable of modeling multiple time periods per day. The DRCOG regional model is capable of estimating congestion over 10 periods of the day and the PPACG model is capable of estimating congestion during three periods. For state highways elsewhere, the 30th highest hourly volume is estimated for highway segments, based primarily on ATR data, and used to estimate peak hour traffic volume and calculate the resulting peak hour volume to capacity ratio. Reporting congestion for only one hour per average weekday severely underestimates congestion in many areas.

Based on this knowledge of previous efforts, and problems associated with each, three questions require resolution for reporting congestion measures in the state: CDOT must define the system coverage for reporting congestion (on- or off-system), the time period for reporting congestion (daily or annually), and the level of aggregation for reporting the measures (statewide, regionally, by county, by corridor, or other).

Research, Analysis, and Recommendation

System Coverage

The purpose behind development of the performance-based investment strategy at CDOT is to link transportation investments to system performance. In other words, to use performance measures in making budgeting and investment programming decisions on state highways. However, CDOT is also obligated to facilitate movement on non-CDOT roadways and by other transportation modes for which they do not make investment decisions. The question at hand is whether CDOT should expend resources to track movement under congested conditions for all transportation facilities or those which CDOT is directly responsible for making investment decisions.

In areas with a population of at least 50,000 persons, the designated metropolitan planning organization (MPO) is responsible for developing criteria and programming funds for transportation expenditures to maximize system performance. CDOT is involved in these decisions as a participating agency and project sponsor, but generally does prioritize the investment of transportation dollars related to major investments. For areas of the state outside of a designated MPO, CDOT is directly responsible for system performance and making major transportation investments on CDOT highways. As a project sponsor, either within or outside an MPO, CDOT is responsible for identifying conditions that require mobility enhancing investment. Within an MPO the actual programming of funds is the responsibility of the MPO. Because CDOT is not directly involved in making investment decisions or tracking system performance for non-CDOT facilities, the agency should not be responsible for tracking system performance on these facilities.

As illustrated in previous discussions regarding development of the inputs to the mobility performance measures, it is difficult within CDOT to develop the appropriate systems for measuring congested conditions on CDOT facilities. Data collection and information processing requirements within CDOT limit the capability to achieve maximum accuracy in reporting the performance measures. Extensive investment in equipment and labor are required to enhance the capability to report vehicle classification, vehicle occupancy, and to more accurately identify congested conditions on state facilities alone. Control of the data inputs to the mobility performance measures is critical for ensuring that consistent information is available to decision makers. CDOT does not have resources identified for data collection on non-CDOT facilities, nor does the department have authority to direct local jurisdictions to invest in the required data collection or conform to CDOT data collection standards for mobility performance measurement purposes.

Considering the combination of the data collection issue (primarily a data quality issue) and the fact that CDOT is not responsible for making transportation investment decision on non-CDOT facilities, it seems appropriate that CDOT concentrate their resources on tracking system performance only for the CDOT system. This means that for areas such as DRCOG and PPACG only mobility performance for the on-system (CDOT highways) network be tracked and reported. **It is recommended that CDOT only report mobility performance measures for the CDOT system.**

Additionally, the majority of state highway miles in Colorado are not subject to congestion on a regular or predictable basis – meaning they are not subject to mobility constraints. Expending resources on extensive data collection and analysis systems will add little value to the investment decision-making process. Criteria should be established for screening potential mobility investment corridors. These criteria should include as a minimum proximity to, or between, areas experiencing above average growth in population of economic production, accessibility to recreational areas, above average recent investment in capital improvements or planning studies, and significance for interstate travel. **It is recommended that CDOT focus mobility performance measurement efforts on a subset of the state system.**

Reporting Time Period

The time period for reporting mobility performance measures relates to reporting congested conditions for typical day, average weekday, average weekend day, annually, or a combination of time periods. Through previous efforts CDOT has reported mobility performance measures on an annual basis. That is, annual hours of congestion, etc. Reporting congestion in terms of annual measures facilitates comparison between corridors or regions by CDOT on a program level basis; however, the purpose of the performance measurement system is to relate system performance to the customer. The customer is more concerned with how congestion affects his/her commute or recreational trip and what transportation agencies are doing to make the trip smoother in terms of the level of congestion, than with knowing the an annual level of congestion.

Reporting annual congestion measures has little meaning to the average traveler in the state. The traveler might ask, "How does that relate to me?" That same traveler can more easily relate to an average weekday, weekend or annual average daily congestion measure for daily person miles of congestion. With such a measure, the average traveler using the system can develop a cognitive relationship to the measure. The individual can judge whether their average daily travel, whichever day that is, falls below, at, or above the average condition. **In order to relate the measures to the customer it is recommended that the measures be reported on an average weekday and average weekend day, in conjunction with total annual congestion.**

In addition to relating system performance to the customer, the investment strategy process must also provide adequate information to decision makers so that they can make program level investment decisions. A daily measure may not be the most desirable for this purpose. In order to make program level investments, the decision makers must be able to relate the problem to the annual budgeting process at a macro level and among the competing program areas. Decision makers must have adequate information to be able to cut expenditures in some program areas in order to increase expenditures in others. **For this reason it is also recommended that annual congestion measures be estimated in conjunction with average weekday and weekend traffic measures.**

Aggregation

Of course, to maximize the relevance of the measures to the average traveler, the measure must also relate to a particular area of the state such as the metropolitan areas, recreational corridors, and rural areas. One statewide daily or annual measure would not accurately portray conditions in any one area of the state or to any single customer segment.

In previous efforts CDOT has estimated the mobility measures statewide, by CDOT region, and for DRCOG and PPACG. As explained above, statewide measures, while appropriate for program level investment decisions, do not relate to the average traveling customer. Also, regional aggregation and mobility performance measures have been found to create a competitive environment among the CDOT regions. Most recently CDOT has expressed interest in reporting mobility performance measures at the corridor level. This approach seems to relieve the competitive nature of reporting measures at the regional level while keeping them at a level the customer can easily relate. **For this reason it is recommended that CDOT continue to pursue reporting the measures at the corridor level while making statewide measures available to decision makers for program level investment.**

URBAN AND RURAL HIGHWAYS

With regards to reporting criteria for urban and rural highways CDOT is interested in whether different thresholds are appropriate for the two components of the highway system. To accomplish this several states were surveyed to identify peer practices. Through this investigation the states of Arizona, California, Florida, Idaho, Minnesota, New Mexico, Texas, and Washington were surveyed. In addition, two national systems, the HPMS and the Highway Economics Requirements System, were examined for differences in urban and rural system performance thresholds.

Research, Analysis, and Recommendations

The following table presents the findings for the investigation:

State/Source	Urban Areas	Rural and Transitional Areas
Colorado	DRCOG = V/C ≥ 0.95 for one or more hours[4] PPACG = V/C ≥ 0.85 for AM and/or PM peak hour Other Areas = undefined or unknown	V/C ≥ 0.85
Arizona	Most Conditions • LOS D for most conditions Peak Hour in Activity Centers (CBD & Similar Density) • LOS E	Rural Areas • LOS B Urban/Rural Transitioning Areas • LOS C
California Note: No specific criteria has been identified	Travel Time Index Absolute delay Auration of delay	AADT
Florida Note: 100th highest hour used to approximate average peak season, peak hour traffic	Interstate (Limited Access and Controlled Access) • LOS C to E depending on facility type and pop. Other State Roads (Multi-lane and Two-lane) • LOS D to E depending on facility type and pop.	Two-lane • LOS C Other Multi-lane • LOS B Transitioning Areas • LOS C
Idaho	Interstate • Near congestion V/C ≥ 0.66 • At congestion V/C ≥ 0.83 Multilane • Near congestion V/C ≥ 0.79 • At congestion V/C ≥ 1.00 Two-lane • Near congestion V/C ≥ 0.60 • At congestion V/C ≥ 1.00	Interstate • Near congestion V/C ≥ 0.75 • At congestion V/C ≥ 0.92 Multilane • Near congestion V/C ≥ 0.75 • At congestion V/C ≥ 0.89 Two-lane • Near congestion V/C ≥ 0.39 • At congestion V/C ≥ 0.62 Plus passing lane congestion measure if all four criteria are met: • AADT > 2,500 • %Trucks ≥ 12% • Terrain = rolling or mountainous • Section length ≥ 2 miles
Minnesota	Twin City Metro Area Goal = maintain <100 congested freeway miles in AM and PM peaks by direction (congestion threshold unknown at time of writing)	Unknown at time of writing
New Mexico	V/C ≥ 1.00	V/C ≥ 0.75
Texas	Areas ≥ 50,000 people • Travel Rate Index (> 1 indicates some congestion) Freeway • 38 mph = heavy; 35 mph = severe; 32 mph = extreme Arterial • 27 mph = heavy; 23 mph = severe; 21 mph	Counts and regression-based forecasting used to predict volume – no congestion threshold for rural areas.

[4] DRCOG considers V/C ≥ 0.85, but only reported V/C ≥ 0.95 for the 2020 RTP process.

State/Source	Urban Areas	Rural and Transitional Areas
	= extreme	
Washington (State)	General Purpose Lanes: • LOS below D or V/C > 0.85 HOV Lanes: • LOS below C or V/C > 0.65	Multi Lane Roads: • LOS below C or V/C > 0.65 Two Lane Roads: • LOS below C or V/C > 0.35
HPMS Analytic Process – Minimum Tolerable Conditions	V/C > 0.85	Flat Terrain: V/C > 0.75 Rolling Terrain: V/C > 0.90 Mountainous Terrain: V/C > 0.95
Highway Economics Requirements System (HERS) – Deficiency-level	V/C > 0.90	Flat Terrain: V/C > 0.70 Rolling Terrain: V/C > 0.80 Mountainous Terrain: V/C > 0.90

The investigation found that:

- Most states/methods differentiate at least urban and rural congestion measures.
- Many states/methods have more than two levels of differentiation.
- Most states consider congestion as one among many other measures (safety/accidents, road condition) when making investment decisions.
- Volume to capacity ratio and LOS are the most common congestion threshold measures.
- Few states reference duration (LOS implies peak hour).

In the most recent CDOT effort, volume to capacity ratios were used to define congestion thresholds in DRCOG, PPACG, and for state highways elsewhere. As the above table illustrates, a different threshold was reported for DRCOG than PPACG and other state highways. This primarily was due to data availability.

The process of reporting system performance measures is relatively new in the transportation profession. This is represented in the wide range of congestion thresholds illustrated in the above table. Findings from practices in other states and information provided in professional guidelines and research papers document that congestion thresholds should be tied to specific LOS levels. A study to determine acceptable congestion thresholds across the state will by design also develop acceptable LOS based thresholds. **Based on the precedence set by previous mobility performance measurement efforts and because there is no standard practice in defining levels of congestion, it is recommended that CDOT continue to pursue reporting congestion at the 0.85 V/C thresholds for both urban and rural highways designated as mobility corridors. In the long term it is recommended that CDOT conduct a study to determine acceptable congestion thresholds in urban and rural areas.**

The recommendation to continue the 0.85 V/C threshold is predicated based on the following:

- A V/C ratio of 0.85 is easily applied across all roadway classifications in the Colorado highway system.
  - A V/C ratio of 0.85 equates to approximately LOS D for facilities with highway speeds of 65-70 mph.
  - Most peer states use a V/C measure in the range of 0.80 to 0.90 as their indicator of “near congestion” or near capacity conditions.
- Statewide uniformity and application of the measure geographically.
  - Colorado geographically has an uneven distribution of population and population centers and has a policy focus on urban-rural equity issues.
  - California, Florida, and Texas have more evenly distributed population and population centers and therefore policy and planning is less focused on urban-rural equity issues.
- A V/C ratio of 0.85 serves as an appropriate “early warning” indicator of congestion.

   - Higher V/C ratios may not provide adequate time for congestion levels requiring a response that includes infrastructure expansion.
   - Lower V/C ratios may be financially unsustainable levels of expectation and prematurely indicate pending congested conditions.
- The V/C ratio of 0.85 fits within current Traffic Data Section methods within CDOT and provides continuity for trend comparisons into the future.

CONGESTION WITH HIGH TRAFFIC DENSITY AND LOW SPEEDS

A condition where congestion exists under high traffic density and low speeds describes level-of-service (LOS) F or worse and is generally referred to as gridlock. At service levels of F and worse flow and speed begin to break down and become unstable. Under these circumstances roadway segments become congested to the point that the flow becomes obstructed and vehicle speeds slow significantly. When speeds slow significantly the number of vehicles passing traffic counters over a period of time decreases and the counters register low volumes by time period. Under these conditions, with volumes decreasing because of slower than desirable speeds, the calculated volume-to-capacity ratio (V/C) decreases suggesting improving conditions. Relying solely on V/C to identify congested conditions in this instance would underestimate the amount of congestion.

In Colorado, these conditions occur primarily in the Denver metropolitan area on sections of the interstate system. The preferred method for alleviating these conditions is to manage the amount of traffic permitted to access the heavily congested segment. In the Denver area, primarily on south I-25, but also on other facilities such as C-470, this is performed through the use of ramp metering. Through ramp metering the travel speeds on specific highway segments are continuously monitored using embedded loops in the travel lanes of the highway. As speeds slow to predetermined levels, a computer program adjusts the rate at which vehicles are allowed to enter the highway using traffic signals located on the access ramps. By slowing the rate at which vehicles are allowed to load onto the highway backups are permitted to clear from congested segments before additional traffic is allowed to worsen the congested conditions.

To overcome the problem illustrated above transportation professionals use a measure of traffic flow density, where density is equal to flow rate (pcphpl) divided by average speed (mph). This concept is discussed in Chapter 3 of the *Highway Capacity Manual*. Table 3.1 in the *Highway Capacity Manual* presents LOS criteria for basic freeway sections and includes in the definition of LOS, a measure of density, speed, volume and V/C for 5 different free-flow speeds ranging from 55 to 75 mph. The 70 mph LOS criteria are reproduced in the following table:

Highway Capacity Manual, Third edition, 1997
Table 3-1. LOS Criteria for Basic Freeway Sections
Free-Flow Speed = 70 mph

LOS	Max Density	Min. Speed	Max. Flow Rate (pcphpl)	Max. V/C
A	10.0	70.0	700	0.29
B	16.0	70.0	1120	0.47
C	24.0	68.0	1632	0.68
D	32.0	64.0	2048	0.85
E	45.0	53.0	2400	1.00
F	var	var	var	Var

The *Highway Capacity Manual* makes no estimate of the LOS criteria beyond LOS E. For LOS F the table suggests that flow rate and speed become unstable and vary in unpredictable ways.

However, given continually decreasing speeds, combined with decreasing flow rates, theoretical density and V/C measures can be calculated. The following table suggests potential density and V/C measures as speed and flow rate continue to decrease beyond standard LOS levels.

Theoretical Continuation of Table 3-1 beyond LOS F
Free-Flow Speed = 70 mph

Max Density	Min. Speed	Max. Flow Rate (pcphpl)	Max. V/C	Den/Speed Ratio
50.0	50.0	2500	1.04	1.00
53.3	45.0	2400	1.00	1.19
57.5	40.0	2300	0.96	1.44
62.9	35.0	2200	0.92	1.80
70.0	30.0	2100	0.88	2.33
80.0	25.0	2000	0.83	3.20

This table clearly illustrates relationships between criteria beyond LOS E levels. As speed and flow rate continue to decrease, the density measure increases (correctly suggesting worsening conditions) and the V/C measure decreases (incorrectly suggesting improving conditions). The ratio of density to speed is added to this table to identify the point at which hourly flow rates reach saturation and begin to decline. This point is approximately where the speed to density ratio begins to exceed 1.0. **Using this illustration as support, it is recommended that CDOT use the density to speed ratio to identify the presence of high-density low speed congestion.**

As described above, identification of high-density low speed conditions is accomplished on facilities where the proper infrastructure exists to monitor travel speeds. Without appropriate monitoring infrastructure identification and management of this condition is not possible on a real-time basis. Lacking proper permanent volume and speed monitoring equipment this condition can only be measured using temporary monitoring equipment.

Identification of facilities with a propensity to exhibit conditions of high-density, slow speed traffic flow is preceded by regularly occurring periods of exceedingly high traffic volumes and worsening LOS estimates. Transportation professionals responsible for traffic management identify these conditions over time though increasingly intense traffic studies that include analysis of travel speed. As worsening traffic conditions develop the level-of-service measured on the segment approaches LOS F on a regular basis. **As flow rates begin to approach the roadway capacity it is recommended that temporary traffic monitoring equipment be employed to measure speed and flow over time in order to identify pending high-density low speed conditions.** [5]

[5] The density, speed, flow rate, and V/C tables above use an hourly flow rate to illustrate the relationship between the four factors. In practice the hourly flow rates should be converted to a shorter time interval such as 15 minutes to accurately capture conditions of high traffic density combined with low speeds.

SECTION III: REQUIRED ENHANCEMENTS TO EXISTING CDOT TRAVEL DATA COLLECTION AND ANALYSIS SYSTEM

This report is focused on short- and long-term improvements to mobility data collection, analysis, and reporting systems. Throughout the report are specific recommendations to improve the mobility performance measurement process. Some of these recommendations relate more to improving data quality for specific measures and have little influence on the overall system. The following recommendations are included elsewhere in the report, but are presented here because of their broad application to multiple mobility performance measures and the overall investment strategy effort at CDOT. These actions are considered to be required enhancements to the system as opposed to improved methodologies.

- Define a mobility subset of the overall state highway system for mobility measurement purposes. This will serve to reduce data quality conflicts and conserve data collection and analysis resources for those corridors most likely to benefit from near-term mobility investments.
- Re-design the seasonal ATR groups for Colorado and take steps to expand the number of ATR locations to better distribute the facilities across all components of the state system.

Of all the recommendations identified by topic area in this report these appear to have the widest span of impact on the state and the overall customer-oriented, performance-based investment strategy.

SECTION IV: SHORT-TERM IMPROVEMENTS

AVERAGE VEHICLE OCCUPANCY SHORT-TERM IMPROVEMENTS

Current Methodology

The current methodology for estimating average vehicle occupancy (AVO) on a statewide basis utilizes accident data obtained from the Colorado Department of Revenue, Division of Motor Vehicles (DMV). Every accident record in the state is filed with the DMV each year. The DMV records the information contained on the accident records and archives that data on computer tape. This tape is subsequently supplied to CDOT on an annual basis for use in analyzing accident locations.

As part of the *Near-term Investment Strategy*, the CDOT Office of Traffic Safety performed a procedure on the 1994 data file to identify AVO by county for accidents involving passenger vehicles. While this process was known at the time to be suspect on certain points, it provided an adequate estimate of AVO to demonstrate the applicability of the performance measure. The employed process involved the following steps:

- Develop a two-dimensional table of the requisite data fields contained on each accident record. These data fields included the number of vehicles involved in the accident, the classification of the vehicles involved (i.e., passenger vehicle, school bus, commercial vehicle, farm equipment, etc.), the number of passengers in each vehicle, and the county in which the accident occurred.
- Next, the data table was sorted by vehicle classification. Only vehicles classified as being in groups 1-4 (passenger vehicles) were used. This step defined the sample set to be used for estimating the AVO.
- Once the appropriate sample data set was defined, the data were sorted by county. The following table presents the results of this effort:

County	AVO	County	AVO	County	AVO
Adams	1.45	Fremont	1.51	Montrose	1.48
Alamosa	1.48	Garfield	1.48	Morgan	1.49
Arapahoe	1.38	Gilpin	1.38	Otero	1.57
Archuleta	1.86	Grand	1.79	Ouray	1.75
Baca	1.80	Gunnison	1.61	Park	1.66
Bent	1.75	Hinsdale	1.58	Phillips	1.41
Boulder	1.38	Huerfano	1.82	Pitkin	1.31
Chaffee	1.75	Jackson	1.80	Prowers	1.53
Cheyenne	1.78	Jefferson	1.44	Pueblo	1.43
Clear Creek	1.98	Kiowa	1.70	Rio Blanco	1.67
Conejos	1.52	Kit Carson	1.58	Rio Grande	1.54
Costilla	1.72	La Plata	1.49	Routt	1.39
Crowley	1.77	Lake	1.43	Saguache	1.81
Custer	1.63	Larimer	1.36	San Juan	1.42
Delta	1.49	Las Animas	1.42	San Miguel	1.57
Denver	1.34	Lincoln	1.66	Sedgwick	1.78
Dolores	1.96	Logan	1.73	Summit	1.61
Douglas	1.54	Mesa	1.41	Teller	1.68
Eagle	1.51	Mineral	1.60	Washington	1.68
El Paso	1.46	Moffat	1.52	Weld	1.49
Elbert	1.69	Montezuma	1.75	Yuma	1.39

This process culminated in a sample data set of over 94,400 crashes involving more than 65,600 passengers. The range in the number of sample crashes by county was from a low of 10 crashes in Hinsdale County to a high of nearly 22,600 in Denver County. Occupants per vehicle are calculated as the number of passengers per county divided by the number of vehicles involved in those crashes. It should be noted that the passenger field in the accident record does not include the driver of the vehicle. One driver per vehicle is added to the passengers to determine total vehicle occupants.

Potential Year 2000 Improvements

Given time constraints to calculate AVO for use in the year 2000 mobility performance measures, it is recommended that the above process be utilized with some adjustments. It has been noted through previous efforts that the above process does not segregate crashes by corridor or time of day. If the most recent accident tape file becomes available in time to perform the required sorts, it is recommended that the crashes be segregated by corridor and time of day as opposed to being segregated only by county. Given that some counties will not result in adequate crash sample data to develop an AVO estimate by corridor and time of day, it is further recommended that multiple years be used to develop the AVO estimates. CDOT is currently in the process of aggregating the most recent three years worth of accident data and has reported that there appears to be enough samples by corridor to generate an adequate estimate of AVO.

For statistical validity, it is felt that a sample size of from 60 to 100 crashes per AM, midday, and PM period by corridor should be adequate to reliably estimate AVO by time period.[6] A table of the actual sample sizes required for a given population ranging between 500 and 10,000 at the 90%, 95%, and 99% confidence level, with a margin of error of 10% is attached as Appendix C.

In a parallel effort, CDOT contracted with a firm to conduct “cluster” counts, including vehicle occupancy observations, at several locations in Denver (28 locations in 6 clusters) and Colorado Springs (5 locations) in the March/April 2000 time frame. Results from these vehicle occupancy observations will be used to validate the accident record methodology.

AVERAGE TRUCK WEIGHT SHORT-TERM IMPROVEMENTS

Average net cargo weight per truck is a component of the Congested Freight Ton-Miles Traveled (CFTMT). It is applied for two categories of composite trucks maintained in the CDOT traffic databases, single-unit trucks and combination trucks. These two truck categories are composed of subsets of the FHWA 13 vehicle-type classification scheme. Single-unit trucks are included in FHWA vehicle types (bins) 5 through 7 and combination trucks are identified as FHWA vehicle types 9 through 13.

Current Methodology

The current values for net cargo weight per truck were provided by CDOT’s Commercial Vehicle Office as part of the previous study. The values are based on samples from the Colorado Department of Revenue’s Ports of Entry (POE). The study (title unknown) reportedly estimated the average weight for single-unit and combination trucks as approximately 26,500 pounds and 61,800 pounds respectively. The study further reportedly suggested that 45.5% of a truck's weight is attributed to freight.

[6] Assuming an acceptable margin of error of 10%, the required sample size at the 90% and 95% confidence level for a population of between 500 and 10,000 ranges from 60 (for a population of 500 at the 90% confidence level) to 96 (for a population of 10,000 at the 95% confidence level).

Potential Year 2000 Improvements

For the year 2000 there are recommendations for improving both the values for average cargo weight per truck type and for the levels of reporting. For the average cargo weight per truck type, it is recommended that data from CDOT's own weigh-in-motion (WIM) sites be used. These data will better represent the actual distribution of truck weights on the road since Port of Entry data are biased towards loaded trucks – POE does include empty trucks in their samples, but many of the empties are allowed to bypass the scales. Furthermore, the rural Port of Entry data primarily captures combination trucks whereas the congested roadways that we are most interested in have a predominance of single-unit trucks since they are mostly located in urban areas. CDOT's WIM sites around the state will provide a good data set for estimating the average gross and cargo weight for combination trucks as statewide values. For single-unit trucks the data from CDOT pavement warranty WIM sites in the Denver metro area on US 36 and on E-470 should be compared to the data from the rural WIM sites before determining which sample data should be used. The Denver metro warranty WIM sites are believed to better represent both the mix of truck types in the single-unit category and the cargo weights for each truck type.

The recommended methodology for computing average gross and cargo weight by truck category is as follows: Compute a net cargo weight using FHWA data on empty (tare) weights for each vehicle class for all "acceptable" non-passenger vehicle WIM records in the data set (i.e., a record that passes data quality tests). These individual average gross vehicle weight and net cargo weight records can then be used to compute average values for combination trucks and single-unit trucks by assigning the individual WIM record to either of these two truck categories.

It is further recommended that CFTMT be reported at a summary level for the year 2000 report because the data are generally not available to confidently report this measure at finer levels. Summary levels include a statewide single value by truck category and statewide by truck category by functional classification of roadway. The data sources that are available and that can be analyzed for this reporting period will generally only provide statewide values for average gross and cargo weight per truck type. Furthermore, the vehicle classification data that are also necessary to support computation of the CFTMT measure are not yet confidently available on corridor-specific basis. If corridor-specific reporting of the CFTMT measure is necessary, it should be clearly noted that statewide values of the average weights are being utilized.

VEHICLE CLASSIFICATION SHORT-TERM IMPROVEMENTS

Vehicle classification data are used to estimate the number of trucks by type in each roadway segment so that average cargo weight values can be applied for the computation of CFTMT. Two composite truck types are used – single-unit trucks and combination vehicles as described in the previous section.

Current Methodology

The current method of estimating vehicle classification is via CDOT's permanent classifier and weigh-in-motion sites and manual classification counts. Very few roadway segments are directly observed as compared to the number for roadways where volume counts are taken. Furthermore, most of the data are available for rural roadways rather than the congested urban roadways that are the focus of this measurement effort.

Potential Year 2000 Improvements

No major changes or new data efforts are recommended for the year 2000 reporting of CFTMT. This is because any improvements in vehicle classification would involve new data collection and analysis schemes that are not feasible within the time frame available. However, a CDOT effort that is currently underway to test and evaluate a "cluster" counting methodology for vehicle classification will provide some limited direct observations that can be incorporated into the computations for the year 2000 reporting.

The cluster counting methodology test is being conducted at several locations in the Denver (28 count locations grouped in 6 clusters) and Colorado Springs (5 count locations) metropolitan areas. These counts will include volume, vehicle classification, and vehicle occupancy observations at most locations. Findings from these efforts will be used to validate the other methodologies employed for year 2000 reporting.

ANNUAL AVERAGE DAILY TRAFFIC, PERCENT TRUCKS, DIRECTIONAL DISTRIBUTION, AND HIGHEST HOURLY VOLUME SHORT-TERM IMPROVEMENTS

Current Methodology

Annual average daily traffic (AADT), directional distribution, and highest hourly volume estimates are currently generated in conjunction with reporting for the Highway Performance Monitoring System (HPMS). The guidelines for HPMS reporting are prescribed by FHWA and presented in the *Traffic Monitoring Guide.* CDOT generally follows these guidelines, with minor modifications, for grouping ATRs and calculating AADT for highway segments across the state. Methodology for estimating vehicle classification by roadway segment (percent trucks) is described previously under the heading Vehicle Classification.

The CDOT Traffic Data Section maintains approximately 72 automatic traffic recorders (ATRs) across the state grouped by seven seasonal groups. Weekly seasonal factors are generated for each ATR and aggregated from each ATR to the group. The seven seasonal groups are identified in the following table along with the number of ATR stations in each seasonal group. A full list of ATR locations by seasonal group is attached as Appendix D.

Seasonal Group	Number of ATR Stations
Rural Interstate	9
Other Rural	27
Recreational	10
High Recreational	3
Urban Interstate	9
Other Urban	6
Special Case (ski area highways)	8
Total	72

Individual ATRs are grouped together into the seasonal groups by common coefficient of variation (CV) of the monthly traffic for each ATR. Seasonal, a term used in the *Traffic Monitoring Guide*, refers to the variability in monthly average day volumes on roadways – the more variation across each week of the year the traffic is said to be more seasonal. The Traffic Data Analysis Section calculates CV as the standard deviation of the monthly average weekday traffic from the annual average daily traffic and expresses the CV as a percentage[7] for each ATR. The ATRs are then grouped using the following definitions for CDOT's seven seasonal ATR groups (group route descriptions are provided by the Traffic Data Analysis Unit).

Seasonal Group	Group Route Description[8]
Group 1 - Rural Interstate	Those routes in the rural area functionally classified as interstate that do not exhibit high seasonal variability. Typically, the CV of the monthly traffic is 10%-25%.
Group 2 - Other Rural	Same as Group 1 except the routes are non-interstate.
Group 3 – Recreational	All routes regardless of functional classification or area type that have a CV of the monthly traffic in the range of 25%-40%.
Group 4 - High Recreational	Same as Group 3 except that the CV of the monthly traffic is greater than 40%.
Group 5 - Urban Interstate	Those routes in urban areas functionally classified as interstate that typically have a CV of the monthly traffic that is less than 10%.
Group 6 - Other Urban	Same as Group 5 except the routes are non-interstate.
Group 7 - Special Case	Those routes with high summer and high winter variations. Typically these are associated with ski area destination routes.

For roadway segments with an ATR station, calculating AADT is a simple exercise of averaging the daily traffic for the entire year. Estimating AADT on roadway segments without an ATR station is slightly more difficult. These roadways are assigned to one of the seven seasonal groups based on available data and professional judgment of how well the seasonal variability of traffic volume aligns with each seasonal group. To calculate AADT for these segments short-term counts (24-48 hour hose counts) are taken on a three-year cycle during the midweek sometime in the summer months. The specific week of the short-term count is then paired with the weekly seasonal factor for the particular ATR group. The average daily traffic volume as measured by the short-term count is multiplied by the weekly seasonal factor to estimate AADT. Analysis of data from each ATR and individual short-term counts is further used to estimate the directional distribution and highest hourly volumes for each roadway segment.

The above seasonal groups were developed for the purpose of HPMS reporting and are believed to be reliable for generating estimates of directional distribution and highest hourly volume as these data items are generated from the actual ATR data. In question is the applicability of using this broad grouping of ATRs and weekday count data to develop estimates of congestion across the state. As an approach to developing recommendations for improved AADT estimates the feasibility of developing additional "mobility" ATR groups and weekday/weekend factors and hourly ATR profiles was examined.

[7] Source: Bob Tenney, CDOT Traffic Data Analysis Unit, notes.
[8] Note: The groups and descriptions are general. Care and judgement should be exercised when assigning groups in areas of transition such as rural to urban, non-recreational to recreational, etc.

Potential Year 2000 Improvements

Preliminary analysis of available ATR data for July 1999 supports development of alternative mobility ATR groups as well as development of weekday and weekend factors. However, through discussions with CDOT DTD staff, it has been determined that the effort would be too extensive to be accomplished for the year 2000 reporting period. Therefore, results of the analysis and the procedures recommended for future improvements have been pushed to the *Potential Long-term Improvements* portion of this section. **For the year 2000 reporting, it is recommended that CDOT continue analysis of ATR data, by the current seasonal groups.**

SECTION V: LONG-TERM IMPROVEMENTS RESEARCH AND RECOMMENDATIONS

AVERAGE VEHICLE OCCUPANCY LONG-TERM IMPROVEMENTS

Alternative Methods

Research on alternative methods for estimating AVO on a statewide level is limited. On a corridor or sub-area basis trip survey and observation survey methods can be economically utilized. Conducting these types of surveys on a statewide basis may not be cost- or time-effective. Some limited research has been conducted on alternative methods, including using statewide accident data. The following two research sources have been reviewed and the methods evaluated for application to CDOT:

- Levine, Ned and M. Wachs. *Factors Affecting Vehicle Occupancy Measurement*. Transportation Research, Volume 32, No. 3, pp. 215-229, Elsevier Science, Ltd., 1998.
- Chang, Li-Yen and F. Mannering. *Predicting Vehicle Occupancies from Accident Data*: An Accident Severity Approach. Transportation Research Record 1635, Paper No. 98-0751, 1998.

Levine and Wachs present a good overview of various observation methods used across the country for determining AVO and examined five factors affecting AVO. Chang and Mannering examined methods for estimating AVO using accident data. The focus of the Chang and Mannering research was to develop adjustment procedures for overcoming tendencies of AVO overestimation when using accident data. Each study is described below along with an evaluation of the alternative methods.

Methods Researched

Factors Affecting Vehicle Occupancy Measurement (Levine and Wachs)

As stated in the introduction to their study, "Our aim is to advance the methodology for vehicle occupancy measurement so that state and local transportation agencies can integrate this measurement into larger transportation policies for reducing congestion and improving the efficiency of road systems." With that said, this report is particularly applicable to CDOT's efforts to improve the estimation of AVO and to aid in developing more effective transportation investment strategies in the future.

Further in the introduction of their study, Levine and Wachs discuss other literature published on the subject. Their literature review reveals that most studies that have been published conclude that AVO varies by time of day and day of week with AVO increasing throughout the day on weekdays and is highest on weekends. In addition, the authors present a brief discussion of the differences in accuracy between roadside observations and review of video data. While they make no decisive concluding statements on which method is more accurate, roadside observations or video, they do report that in one experiment conducted by the California Highway Patrol and Caltrans in which both methods were applied to the same roadway segments, the photographic interpreters disagreed with the visual observers on approximately 20-25% of the observations. In another experiment in California, highway patrol officers pursued HOV lane vehicles suspected of violating the vehicle occupancy requirements based on information from either people monitoring video equipment or people monitoring vehicle occupancy from the roadside. The study found that in both instances "the direct observers and the video observers overestimated the number of vehicles violating the occupancy requirements." On further observation of the videotapes by experienced Caltrans employees Caltrans determined that the videotapes were more accurate, but at about twice the cost. A comparable study in New Jersey came to similar conclusions regarding increased accuracy from video equipment, but at a much higher cost.

The remainder of the study focuses on utilizing five vehicle occupancy data sets from different sources in California to determine the effect of data set differences in AVO, time of day variation, day of week variation, road class variation, the effect of HOV lanes on AVO, and the effect of traffic volume on AVO. Overall data set differences in AVO among the five data sets were not identifiable. Each resulted in similar AVO, standard deviation, and range of AVO. With regards to time of day, each data set showed an increase in AVO throughout the day, peaking in the late afternoon and early evening. The researchers conclude that weighting morning and evening observations can predict a reasonably close estimate of AVO for the entire day. As for day of week, the data sets revealed that there was practically no difference in AVO results for Monday through Friday, but that AVO did consistently increase in all data sets on Saturdays. By road class, the data sets showed considerable variation in AVO. With two of the data sets AVO decreased as road class increased with freeways having the lowest AVO and local roads having the highest. In another data set no difference in AVO was present for the two road classes included in the data set. In the remaining two data sets, freeway AVO was lowest, but major arterial AVO was higher than minor arterial AVO. Levine and Wachs conclude that road classes are used for different trip purposes in different metropolitan areas. The findings with regards to HOV lanes and their effect on highway segment AVO produced expected results with higher AVO (or person throughput) on segments with HOV lanes than on segments without HOV lanes. The final factor examined was traffic volume. Roadway segments in the data sets were divided into high volume segments and low volume segments. Analysis of the data sets varied with regards to differences in AVO on high volume versus low volume segments. One data set revealed that high volume segments had significantly higher AVO than low volume segments, while other data sets were less conclusive.

Through this analysis Levine and Wachs conclude that AVO varies by location, volume level, and facility type. They found that AVO varies by district, area, and neighborhood. This supports CDOT's efforts to use segment or location specific estimates of AVO as opposed to a statewide or regional AVO. Levine and Wachs further note that variables affecting AVO are unique to certain areas and facilities and must be identified in the areas of concern prior to establishing a recurring sampling plan.

Predicting Vehicle Occupancies from Accident Data (Chang and Mannering)

Chang and Mannering open their study by stating that intuitively the use of accident data should be a good source for obtaining estimates of AVO. This is because most accident reports identify the number of persons in each vehicle and the data is stored electronically, making access and analysis easier. However, they also state that other researchers have found that accident data usually overestimates AVO due to a relationship between accident severity and higher vehicle occupancy (high occupancy vehicle crashes tend to result in more severe accidents that in turn are more likely to be reported). Their study sought to “develop a methodological approach that explicitly accounts for the relationship between vehicle occupancy and severity and to use this as a basis for predicting vehicle occupancy from accident data.” In other words, the purpose of the study was to account for the relationship in accident severity and vehicle occupancy and develop factors for avoiding the overestimation of vehicle occupancy when using accident data. The purpose was not to identify the reasons for the relationship between accident severity and vehicle occupancy.

The researchers developed a nested logit model to estimate the probability of different occupancies and the probability of different accident severities. Predictive results from the model were then compared with actual observations for the same roadways to determine the appropriate adjustment factors to be applied in the model. The differences between the model and the actual observations for specific roadway segments in the study were as follows:

- Single occupant vehicles – the model predicted 74.9% of the vehicle population while observations resulted in an estimate of 85.1% of the vehicle population.
- Two-occupant vehicles – the model predicted 17.0% of the vehicle population while observations resulted in an estimate of 12.0% of the vehicle population.
- Three-occupant vehicles – the model predicted 4.7% of the vehicle population while observations resulted in an estimate of 1.4% of the vehicle population.
- Four or more occupant vehicles – the model predicted 3.4% of the vehicle population while observations resulted in an estimate of 1.5% of the vehicle population.

According to the researchers "with the adjusted constants, the accuracy of model prediction is significantly increased." Particular advantages of the model technique, according to the researchers, are that it is easy and inexpensive, accurate, flexible, and transferable.

<u>Survey Methods for Estimating AVO</u>

The following discussions present alternative survey techniques that have potential for application by CDOT in estimating AVO. The techniques are grouped into two classes: Observation surveys and traveler solicitation surveys.

- Observation Surveys – The Levine and Wachs discussion above suggested two approaches for conducting roadside observation surveys. These were video observations and manual roadside observations. While they suggest that video observations may be more accurate, they also point out that the cost is approximately twice that of manual roadside observations. Given the moderate increase in accuracy in combination with the significantly higher cost of video observations this option is not attractive.

- Traveler Solicitation Surveys – For these purposes, traveler solicitation surveys are defined as surveys requiring the active participation of travelers across the state. These surveys can take the form of random telephone surveys or trip diaries. CDOT and other Colorado jurisdictions have used both techniques in the past to achieve differing goals. DRCOG and other MPOs use trip diaries to analyze regional travel demand models. CDOT and the state legislature use telephone surveys to estimate public opinion with regards to transportation issues. Trip diaries have a high level of accuracy associated with them, but are very expensive to conduct and analyze. Sample sizes must be significantly higher for trip diary surveys than telephone surveys to account for lower response rates. Telephone surveys can be conducted at relatively affordable expense, but accuracy levels are difficult to estimate. In combination, the two can be used to validate each other.

Evaluation of Research Results

The Levine and Wachs study supports the use of AVO sampling at the local level and that roadside human observation, while slightly less accurate than video observation, is more cost-effective. This approach is consistent with other manual data collection methods employed at CDOT and across the state. The installation and analysis of video monitoring equipment across the state seems outside of CDOT's funding and maintenance capabilities over the next few years. At a few significant high volume locations it may prove beneficial to incorporate video surveillance for observing vehicle occupancy with other traffic monitoring equipment as data collection technology at CDOT advances.

Chan and Mannering's approach to developing a predictive model to estimate AVO using accident data is interesting and potentially very feasible within CDOT's current business practices. However, it is noted that such a model must be validated with field observations on a periodic basis.

Recommended Long-term Improvements

Multiple approaches to estimating AVO were presented above as potential long-term improvements to be employed by CDOT for the purpose of estimating AVO across the state. These approaches included developing a predictive model of AVO based on accident records, manual field observation surveys, telephone surveys, and trip diaries.

The recommended overall improvement is to combine the model approach with the manual field observation surveys to further enhance the short-term improvements made to estimating AVO from accident records. **Based on the research identified, it is recommended in the long term that CDOT develop a model of accident data to predict vehicle occupancy by major facility across the state. It is further recommended that CDOT conduct periodic roadside manual observation surveys to validate the model results.**

AVERAGE TRUCK WEIGHT LONG-TERM IMPROVEMENTS

Alternative Methods

Other alternatives to the current short-term improvements approach were considered. These include:

- Use of portable load cell devices to sample the weights of urban trucks, especially the single-unit vehicles.
- Conduct a CDOT study of urban area trucking firms to improve the estimate of truck loading characteristics, especially for the single-unit truck.
- Identify research results by others in the area of urban truck types and weights.
- Re-consider the need for and value of truck weight in the Mobility Performance Measures Reporting program and instead consider a truck miles of travel under congested conditions measure

Recommended Long-term Improvements

No long-term recommendations are made to improve the average truck weight values for the single-unit and combination vehicles used in computing and reporting Congested Freight Ton Miles Traveled (CFTMT) beyond the short-term ideas already under consideration. Refinement of the average truck weight values, which merely applies a statewide constant that in essence represents the assumed relative economic value between single-unit and combination vehicles, adds very little decision-critical information to the congested truck miles (by type) component of the CFTMT measure. (Corridor and direction-specific average truck weight values as opposed to statewide averages would be even more challenging to determine.) The DRCOG Congestion Management System (CMS), for example, does not even use truck weights but instead reports only congested truck miles of travel under congested conditions. Furthermore, since most of the congested roadway hours in the state are on urban area roadway segments, the importance of the average truck weight factors in further discriminating between the urban and rural impacts of congestion on trucking is largely diminished. The more critical objective in the reporting of CFTMT is the stability of the measure over time for trend analysis and interpretation rather than the accuracy of its absolute value. This stability objective can be achieved with the current average truck weights without further effort. It appears to be more valuable to the overall reporting program to assign available resources to the truck classification data collection effort rather than to the average truck weight data collection effort.

VEHICLE CLASSIFICATION LONG-TERM IMPROVEMENTS

Alternative Methods

Several alternative approaches to the currently available data for estimating the two-type truck volume on congested roadway segments were investigated. These include:

- Additional manual classification counts using various sampling strategies.
- Use of data that might be obtained from CDOT's Intelligent Transportation System (ITS) program.
- Use of new portable radar detectors that are being tested by CDOT for traffic volume counts.
- Results of other research on truck volume data collection and estimating – Washington State DOT.[9]

The additional manual classification counts included fixed-site counts (i.e., data collection person stays at a single site for the duration of the count) and "cluster counts" where the data collection person rotates among several adjacent locations for very short "bursts" of data collection at each site. Use of ITS data focused on the possibility of obtaining length-based classification from the dual-loop speed-density installations used by the Traffic Operations Center. Fortunately, the installation of ITS instrumentation is generally located on the high volume congested roadway segments that are also the focus of the performance measure efforts. The new portable radar detectors that are currently being evaluated potentially could provide a multi-lane two-bin vehicle classification based on vehicle size in a side-mounted installation or a 7-bin single-lane classification in a forward-mounted installation. Outside research into the truck travel behavior reviewed the results of an extensive 5-year effort by Washington State DOT and the University of Washington to determine whether seasonal factors could be developed and applied to short-duration classification counts to better estimate average annual conditions.

Methods Researched

Manual two-direction classification counts for three two-hour periods in a single weekday were recommended in the Congestion Management System (CMS) Performance Monitoring Plan at least once every three years at each control site. These three two-hour periods were to cover the morning peak period, afternoon/evening peak period, and a midday period. CDOT's recent test of a cluster count approach to improve geographic coverage by having the data observer rotate among several nearby locations appears to have potentially reasonable results that could significantly reduce the cost of the data collection effort while improving data availability and quality over that currently available. The investigation of the use of ITS speed-density installations was not completed as it was dropped from the project scope of work part way through the effort but the concept appears sound and promising. The extensive Washington State research concluded that the development of seasonal factors to apply to a single annual short-duration (24 or 48 hour) classification count was not reasonable to obtain the desired accuracy. That study then recommended that four weeklong classification counts be used at each site to

[9] *Truck Loads and Flows*; Washington State Transportation Center, University of Washington, Seattle, WA; Contract #T9233; November 1993.

obtain the desired accuracy but recognized the financial impacts of such an approach. Nevertheless, this study did develop an approach and procedure for seasonal adjustments to short-duration classification counts that might hold some potential applicability to CDOT's situation.

Recommended Long-term Improvements

Based on the research to date and the preliminary results from CDOT's cluster count tests, it is recommended that the Department take the following actions with regard to improving the vehicle classification data to support the Mobility Performance Measures Program.

- Continue and expand the classification "cluster count" approach while simultaneously completing a more thorough evaluation of data availability, data quality, and cost.
- Further investigate the possible use of ITS speed-density loop installations for length-based classification.

The combination of these two approaches should provide the Department with an effective and affordable method for obtaining the vehicle classification data at an acceptable accuracy, coverage, and cost.

MOST EFFECTIVE TEMPORARY DATA COLLECTION STRATEGY

In support of the recommendation to report mobility performance measures on specified mobility corridors it is further recommended that CDOT examine the potential for increasing temporary data collection efforts on the associated corridors. With respect to statewide temporary data collection CDOT should continue to pursue the recommendations outlined in the *Traffic Monitoring Strategic Plan* developed for CDOT in approximately 1996. CDOT has invoked many of these recommendations including contracting the temporary counts to private firms. Should CDOT decide to pursue mobility performance measure reporting on a limited set of specific mobility corridors temporary count efforts should receive increased focus on these corridors.

With regards to recommendations for additional permanent ATR sites, the *Traffic Monitoring Strategic Plan* recommended that ATR equipment be installed as part of all future roadway construction projects and be funded out of the construction budget. The inclusion of ATR equipment as part of roadway construction projects would be insignificant in terms of the total construction budget. In conjunction with adding ATR sites across the state CDOT also requires additional operating and maintenance funds to keep the existing and new ATR sites working. Adding additional sites through this process will facilitate the development of additional seasonal groups and provide a more accurate means for assigning temporary count locations to the appropriate seasonal groups based on similar coefficient of variation patterns. **For these reasons, it is recommended that CDOT continue to pursue the implementation of additional ATR locations and increase the budget for ATR maintenance activities as recommended in the *Traffic Monitoring Strategic Plan*. As for temporary count practices, it is further recommended that CDOT extend all rural temporary counts to 48 hours and add additional temporary counts in other seasons to supplement the summer count program.**

ANNUAL AVERAGE DAILY TRAFFIC, PERCENT TRUCKS, DIRECTIONAL DISTRIBUTION, AND HIGHEST HOURLY VOLUME LONG-TERM IMPROVEMENTS

Alternative Methods

An initial assessment of using the existing methodology for estimating AADT, and eventually hours of congestion, reveals that improvements for more accurate estimates can be achieved. The presumption behind the analysis consists of two components: (1) the existing ATR groups may not be sufficient to reflect the wide range of variation in traffic patterns across the state, and (2) the use of weekday counts may mask congestion occurring on the weekends, thus underreporting congested conditions across the state. Sample data from six ATR stations across the state for July 1999 was obtained to test these presumptions. The resulting analysis is described under the recommended long-term improvements section. The following discussions summarize the research conducted for identifying alternative approaches to improving AADT estimates.

Methods Researched

Using Factor Analysis for Assigning AADT Expansion Factors

Many research efforts continue to examine the statistical precision of AADT estimates derived from short-period traffic counts taken with ATRs. In a research effort in Minnesota and Canada, the effects of various factors on estimation errors were explored. The researchers expressed the appropriateness of volume adjustment factors in terms of assignment effectiveness (a statistical comparison of seasonal traffic counts to ATR counts using mean squared error), which mirrors the degree of correctness with which a sample site is assigned to an ATR group. Investigators found that AADT estimation errors are very sensitive to the assignment effectiveness, and indicated that highway agencies should put more emphasis on sample site assignments to correct ATR groups than on the duration of count. For correct assignment of a sample site to an ATR group, the researchers suggest that two seasonal counts of at least 7 days duration are needed; four seasonal counts greatly improve accuracy. Sampling length was most important on recreational routes; no difference in accuracy was found for commuter routes with samples of 24, 48, and 72 hours.

A New Zealand research project found that considerable reduction of effort in the counting process could be achieved by identifying key factors that may allow for grouping of roads into similar groups. The researchers identified ten major groups of roads by studying the hourly traffic patterns, over several years. The primary analytic method was that of hierarchical cluster analysis on the daily flows.

Source(s):

- *Traffic Stream Data, Road Categories and Traffic Count Strategies*; Transfund New Zealand Research Report; 1997.
- *Statewide Traffic Volume Studies and Precision of AADT Estimates*; Journal of Transportation Engineering; Vol. 122, No 6; 1996.
- *Duration and Frequency of Seasonal Traffic Counts*; Journal of Transportation Engineering; Vol. 119 No 3.
- *Seasonal Traffic Counts for a Precise Estimation of AADT*; ITE Journal; Vol. 64 No 7.
- *Accuracy of Estimates of Mean Daily Traffic*; Transportation Research Record 1593.

Other Methods for Assigning AADT Expansion Factors

Researchers in Minnesota tested a neural network approach as an alternative to the traditional factor approach for estimating AADT from 48-hour sample counts. While researchers found that estimation errors for the factor approach can be lower under a scenario in which ATR sites are grouped appropriately and the sample sites are correctly assigned to various ATR groups, there is currently little guidance on how to achieve the assignment accuracy. The advantage of the neural network approach is that classification of ATR sites and sample site assignments are not required. The neural network approach can be particularly suitable for estimating AADT from two or more short-period traffic counts taken at different times during the counting season.

Researchers in Delaware tested a regression approach for determining seasonal adjustment factors as an alternative to traditional cluster analysis. The regression approach produced more reliable adjustment factors. This research also addressed the appropriate number of ATR stations to produce reliable adjustments.

Source(s):

- *Neural Networks as Alternative to Traditional Factor Approach to Annual Average Daily Traffic Estimation from Traffic Counts*; Transportation Research Record 1660, 1999.
- *Estimation of AADT on Low-Volume Roads: The Factor Approach Versus Neural Networks*; Presented at the 79th Annual Meeting of the Transportation Research Board; January 2000.
- *Development and Evaluation of a Statistically Reliable Traffic Counting Program*; Transportation Planning and Technology; Vol. 18, No 3; 1994.

Reducing Sampling Errors in AADT Estimates

Researchers in Norway tested a regression approach to estimating AADT from short-period traffic counts. This method uses the fact that traffic levels may vary considerably between count sites, but that variations are usually very similar between sites, especially within the same car length class. It is more precise than the traditional factor approach, and specifies the precision of the AADT estimate as a function of the sample design. This precision function can be used to optimize the sample design before counting starts.

Researchers in Iowa analyzed to what extent day of week/month of year factors can reduce the error of prediction of AADT from a short-term traffic count, utilizing data from an ATR station maintained by the Iowa DOT in Cedar Rapids, Iowa. The benefits of factoring are shown to be a one-quarter reduction in error of AADT prediction for a 24-hour count at this station, with minimal added benefit of a (consecutive) multiple-day count. While the U.S. DOT has also published estimates of sample error as a function of the volume in an unfactored count, there is no guidance as to how much (sampling) error remains in the estimation of AADT from a factored short-term count in urban areas. The Iowa research can be used to help determine whether changes in counted volume over time represent a significant change in traffic flow or not.

FHWA continues to study the variability in the traffic data from the continuously monitored road segments from state(s) and, the extent to which this variability is transferred to and affects the precision of the data produced from the road segments which are monitored only one or two days each year. FHWA aims to provide a statement that expresses the accuracy of AADT estimates is in terms of its estimated variability or precision, which will likely be expressed as a coefficient of variation.

Source(s):

- *Traffic Volume Estimation from Short-Period Traffic Counts*; Traffic Engineering and Control; Vol. 39, No 12; 1998.
- *The Impact of Factoring Traffic Counts for Daily and Monthly Variation in Reducing Sample Counting Error*; Proceedings from the Crossroads 2000 Conference; Iowa State University; 1998.
- *Variability in Continuous Traffic Monitoring Data*; Proceedings of the National Traffic Data Acquisition Conference; 1996.

Estimating AADT without Traffic Counts

Researchers in Florida, Indiana, Minnesota and Kentucky have developed prediction models for estimating AADT in the absence of traffic counts. Most of these models use a regression approach that incorporates some set of roadway characteristics, socioeconomics, and roadway connectivity as independent variables. The research efforts have met with varying levels of success (as measured by statistical parameters). The final Florida model included number of lanes, functional class, area type, proximity to other non-state roads, number of registered autos within ¼ mile of road, and service employment; the resulting model had a large negative intercept that could affect results on low-volume roads. Data analysis suggested that the functional class used in the model should be based on road use rather than ownership characteristics.

Source(s):

- *Estimation of Annual Average Daily Traffic for Nonstate Roads in a Florida County*; Transportation Research Record 1660; 1999.

Estimating Directional Distribution and Highest Hourly Volume from Short-term (temporary) Counts

Directional distribution refers to the proportion of traffic that occurs on a facility in each travel direction. For separated facilities and facilities with ATR sites directional distribution is measured from directional counts – either continuous ATR or temporary hose counts. A problem exists in assigning an appropriate directional distribution to two-lane bi-directional facilities. The existing temporary count program does not provide for directional counts on two-lane facilities. In an associated effort to this project CDOT determined that only one location in the state exists where directional distribution cannot be estimated from a continuous ATR counter. Adding directional counts to the count program will alleviate this problem – particularly in the area where other methods cannot be used. Because this problem exists for a limited number of locations the added cost will be marginal.

To estimate hourly volume on roadway segments CDOT uses the 30th highest observed hour. This is particularly appropriate for rural highways and is a commonly accepted practice for defining the design hour capacity of the roadway, although in some instances design hours are selected between the 30th highest hour and the 100th highest hour. While use of the 30th highest hour is common practice, the *Highway Capacity Manual* points out that the selection of the design hour between the 30th highest hour and the 100th highest hour "is not a rigid criterion and indicates the need for local data on which to make informed decisions."

The capacity manual further explains that in urban areas with lower variation in seasonal hourly volumes the highest hourly volumes can be as little as 15 percent greater than the 100th highest hour and for recreation routes with high variation in seasonal hourly volumes the highest hours can be as much as twice the 100th highest hour. From this information it appears that there is little difference between the highest hourly volumes and the 100th highest hourly volume in urban areas making it relatively insignificant which hour is selected as the design hour. For recreational corridors, with higher hourly variation in traffic volume, it becomes more critical in selecting which hour to represent as the design hour. In addition, all recreational corridors do not exhibit the same seasonal variation in hourly volumes. For this reason it may be inappropriate in some instances to use a standard design hour as the highest hourly volume.

To overcome this situation in highly recreational corridors the National Park Service commonly uses the 85^{th} percentile as the design hour volume. This is a standard practice authorized by the park service and ensures that roadway facilities are not overly designed to account for relatively infrequent, but exceedingly high traffic volumes on peak days.

Evaluation of Research Results

- AADT estimates are sensitive to the assignment of roadway segments to ATR groups. For correct assignment of a sample site to an ATR group, at least two seasonal counts of 7 days duration are needed; four seasonal counts greatly improve accuracy.
- Researchers in New Zealand were able to reduce counting effort through identification of key factors and grouping roads into 10 major groups by studying hourly traffic patterns, over several years.
- Researchers in Minnesota found that properly grouping ATR sites and correctly assigning sample sites to the ATR groups could lower estimation errors. The researchers also used two or more short-period traffic counts taken at different times during the counting season. However, they noted there is little guidance on how to achieve the assignment accuracy.
- A group of researchers in Florida, Indiana, Minnesota, and Kentucky found varying results from using prediction models based on a regression approach to estimate AADT on sample segments lacking traffic counts.

Recommended Long-term Improvements

As much of the above research indicates, estimation error can be improved through alternative methods of assigning sample sites to ATR groups and classifying the ATR groups. Generally, research suggests that using multiple short-term counts across at least two seasons helps to decrease assignment error. Currently CDOT conducts 24-48 hour counts at sample sites every three years. None of the research was able to provide a description of measuring the increased accuracy across a system. The following discussion focuses on the development of the mobility ATR groups. **It is recommended that CDOT re-examine the current ATR groups and segment assignment procedures. Specifically, multiple season samples should be conducted to gain a better understanding of the seasonal fluctuations in traffic flows. This will be especially useful for the proper assignment of recreational roads. This recommendation is consistent with previous recommendations to develop alternative mobility ATR groups.**

It is further recommended that CDOT adjust the temporary count program by adding directional tube counts to provide for the collection of directional distribution information at locations lacking estimation means. In addition, it is recommended that CDOT perform an analysis to determine the appropriateness of using the 85^{th} percentile in replacement of the 30^{th} highest hour for determining the highest hourly volume (design hour) on rural recreational corridors while maintaining the 30^{th} highest hour for urban corridors for reporting volume to capacity ratios.

Mobility ATR Groups

For the purpose of reporting AADT based on weekly volumes, the existing seasonal groups appear to be sufficient. However, for the purpose of reporting statewide mobility measures, it is believed the groups could be improved.

The previously described CDOT seasonal groups categorize roadway segments by a combination of seasonal variation and roadway classification with little reference to geographic location other than urban versus rural and ski area highways. Lacking the data to make a quantitative assessment, a general assessment based on familiarity with statewide travel patterns reveals that trip purposes and characteristics likely vary throughout the state to a greater degree than is captured and represented by the existing seven seasonal groupings. Adding groups to the state system will require an investment in additional ATR locations. The *Traffic Monitoring Guide* recommends 5-8 ATR stations per group as a general rule to achieve 10% precision with 95% confidence. The following table supports a potential redistribution of ATR stations into a broader number of mobility ATR groups.

Seasonal Group	Number of ATR Stations	Coefficient of Variation
1 - Rural Interstate	9	10%-25%
2 - Other Rural	27	10%-25%
3 – Recreational	10	25%-40%
4 - High Recreational	3	>40%
5 - Urban Interstate	9	<10%
6 - Other Urban	6	<10%
7 - Special Case (Ski area highways)	8	High Summer and Winter Variation
Total	72	

As the table illustrates, CDOT maintains 72 ATR stations across seven seasonal groups with the majority (38%) located on other rural roadways. This number of stations could potentially support up to nine mobility ATR groups. The "Rural Interstate" and "Other Urban" seasonal groups can be assumed to accurately reflect consistent seasonal variations based on common professional understanding of traffic patterns on these functional class roadways without regard to "where" in the state they are located. However, the remaining groups may be subject to debate on consistent traffic patterns across the state. For example, Other Rural as currently classified includes roadway segments on the Western and Eastern Slopes as well as the mountain areas of the state even though these areas contain different settlement patterns and are supported by different economic bases. While Western Slope and Eastern Slope areas of the state are broadly classified as agricultural communities the Western slope is more reliant on livestock ranching activities and the Eastern Slope is based more heavily on farming activities. Each of these activities generates different travel patterns at different times of the year. At the same time mountain communities rely on a combination of recreational tourism and agriculture. Based on this knowledge it may be beneficial for CDOT to investigate regrouping of the ATR stations to more accurately reflect these differences. Regrouping the Other Rural, Recreational, High Recreational, and Special Case seasonal groups – a total of 48 ATR stations – could potentially result in up to six new ATR groups with eight stations per group. A detailed analysis of the ATR stations to include examination of geographic coverage is warranted to determine the resulting difference in accuracy achieved in estimating AADT from the additional groups.

Weekday/Weekend Variation

An additional concern in calculating AADT and directional distribution for the purpose of estimating congested conditions (hours of congestion) across the state is the uncertainty in accurately reflecting the daily traffic volume and measure of average daily congestion using AADT estimates developed from weekly volumes – without regard for weekend volumes. To test this methodology, an analysis was conducted on data obtained for the month of July 1999 for six ATR sites, by direction, from around the state. This data was obtained from the CDOT Traffic Data Analysis Unit. Results of the analysis suggest that weekdays and weekends should be considered separately when estimating levels of congestion. Average weekday factors ignore weekend traffic volumes. In some heavy recreational corridors, a higher proportion of traffic is present on the weekends that may be traveling under congested conditions.

The table that follows illustrates the difference in the ratio of traffic on weekdays and weekends to the average daily traffic as calculated for the entire month. Stations exhibiting a weekend factor greater than 1.0 are representative of locations where weekend congestion may not be captured from using AADT calculated over the entire year or from estimating AADT from one weekday short-term count and a weekly AADT factor.

Station	Direction	Location	Weekend	Monthly ADT	Avg. Weekday Traffic	Avg. Weekend Daily Traffic	Weekday Factor	Weekend Factor
105	Eastbound	I-70 east of Glenwood Springs	Fri-Sun	10,100	9,613	10,983	0.95	1.09
105	Westbound	I-70 east of Glenwood Springs	Fri-Sun	9,953	9,217	10,846	0.93	1.09
205	Eastbound	US 34 near Estes Park	Fri-Sun	4,641	4,473	4,855	0.96	1.05
205	Westbound	US 34 near Estes Park	Fri-Sun	4,529	4,311	4,807	0.95	1.06
217	Eastbound	US 160 (east of Durango)	Fri-Sun	5,098	5,248	4,916	1.03	0.96
217	Westbound	US 160 (east of Durango)	Fri-Sun	5,048	5,211	4,850	1.03	0.96
504	Eastbound	US 36 south of US 287	Sat-Sun	39,177	43,163	30,320	1.10	0.77
504	Westbound	US 36 south of US 287	Sat-Sun	39,393	43,451	30,375	1.10	0.77
507	Eastbound	I-270 at I-76	Sat-Sun	40,088	44,433	31,962	1.11	0.80
507	Westbound	I-270 at I-76	Sat-Sun	41,303	45,389	33,561	1.10	0.81
1062	Eastbound	I-70 at Eisenhower Tunnel, West Portal	Fri-Sun	15,972	13,873	18,521	0.89	1.13
1063	Westbound	I-70 at Eisenhower Tunnel, West Portal	Fri-Sun	16,549	13,314	20,478	0.83	1.21

This analysis supports the recommendation that weekday and weekend ATR hourly profiles and seasonal factors by week of the year be developed for each ATR seasonal group to more accurately report congestion levels.[10] However, time does not permit to develop these additional profiles and weekend factors for year 2000 reporting, in which case it is highly suggested that the additional hourly profiles and weekly weekday/weekend factors be developed in the near future. Appendix E consists of charts developed to illustrate the difference between weekday and weekend daily and hourly traffic levels for the six ATR stations by direction. The charts show a wide variation in traffic characteristics between the weekdays and weekends at most of the stations.

[10] It has further been noted by members of the Study Panel that some ATR locations do not coincide with the implied meaning behind the seasonal group names. As additional ATR seasonal groups are developed it is recommended that the naming convention used for the groups be changed to more accurately reflect the statistical commonalities behind the groups rather than the geographical location or functional classification of the majority of the roadways within the group.

APPENDIX A
Near-term Investment Program – Mobility Performance Measure Calculations

The following table has been reproduced from *Table 3 – Mobility Measures*, as it originally appeared in *Appendix A: Documentation of Mobility Measures, Near-term Investment Program*.

Measure	Calculation	Data Source
Vehicle Miles Traveled	Σ [(Total ADT – SU ADT – Comb. ADT) x (Segment Length)]	ADT is calculated by Bob Tenney, CDOT Traffic Monitoring. SU and combination truck ADT must be subtracted from total ADT to determine general auto ADT. Segment length is a data field contained in IRIS and the condense files.
PMT	Σ (VMT x Average Vehicle Occupancy)	Mike Dineen, CDOT OTS, calculated vehicle occupancy for each county. Source data for the calculation was statewide accident records identifying the total number of vehicles and persons in each vehicle involved in and accident in each county. County figures were then aggregated up to the CDOT Regions.
Truck VMT	Σ [(SU ADT + Comb. ADT) x (segment length)]	SU and Comb. ADT came from Bob Tenney.
Truck Freight Ton-Miles Traveled	Σ (Truck VMT x Avg. tons of freight per vehicle)	Average tons of freight per vehicle was calculated by factoring the average vehicle weight for both SU and comb. Trucks by 54.5% - the estimated percentage of total vehicle weight created by freight.
Average Speed	Σ [(segment length) / (segment congested travel time) x (segment PMT)] / Σ (PMT)	Segment congested travel time is the time it would take to travel the length of the segment under congested conditions.
FFTT/Cong. TT	Σ (FFTT) / Σ (Cong. TT)	Free-flow travel time is the time for one vehicle to travel the length of the segment without congestion. FFTT divided by congested TT represents the proportion of travel time consumed by congestion.
Lost Person Hours	Σ [(congested TT x PMT) – (FFTT x PMT)]	Total person hours under congestion were computed for each segment using a speed curve based on the posted speed limit and the level of congestion (V/C). ADT was factored for the peak and shoulder periods of that total ADT on the segment was not subjected to congested conditions.
Lost Freight Hours	Σ [(congested TT x FTMT) – (FFTT x FTMT)]	See above.
Highway Miles	Σ (segment length)	Highway miles are centerline miles and are included per segment in IRIS.
Congested Highway Miles	Σ (highway segments lengths with a V/C greater than 0.85)	The congestion management system defines congestion as a roadway segment with a V/C ratio greater than 0.85. Volume to capacity is computed as ADT / segment capacity. Segment capacities were computed by Bob Tenney, CDOT Traffic Monitoring.
Passenger Mobility Index (MI)	PMT / VMT x Average Speed	Comparative index of person mobility.
Freight Mobility Index (MI)	FTMT / Truck VMT x Average Speed	Comparative index of freight mobility.
Passenger Mobility Coefficient (MC)	PMT x Average Speed / 1,000,000	Dividing by 1,000,000 facilitates comparison of the different factors.
Freight Mobility Coefficient	FTMT x Average Speed / 1,000,000	Dividing by 1,000,000 facilitates comparison of the different factors.
VMT / Person	Self-explanatory.	Comparative measure of VMT per person in the region or state.
PMT / VMT	Self-explanatory.	Comparative measure of PMT per VMT.
FTMT / Truck VMT	Self-explanatory.	Comparative measure of FTMT per Truck VMT.

APPENDIX B
CDOT Transportation Investment Strategy – Mobility Performance Measure Calculations

The attached pages were taken from the Appendix: Documentation for Mobility and Program Delivery Performance Measures, October 25, 1999, as prepared for the *CDOT Investment Strategy* report. Only the portion of the appendix related to mobility performance measures is reproduced here. These calculations represent the state of the practice at the time the report was generated. As part of the current and continuing *CDOT Travel Database Improvement Research Project* these methods will be improved. It is also noted that in several instances data are referenced as "collected" when in actuality they are either collected or estimated.

Mobility Performance Measures

The following performance measures were developed for the Mobility Investment Category[1]:

1. Person Miles of Travel Under Congested Conditions - Denver
2. Person Miles of Travel Under Congested Conditions - Colorado Springs
3. Person Miles of Travel Under Congested Conditions - State Highways Elsewhere
4. Freight Ton-Miles of travel Under Congested Conditions - Denver
5. Freight Ton-Miles of Travel Under Congested Conditions - Colorado Springs
6. Freight Ton-Miles of Travel Under Congested Conditions - State Highways Elsewhere
7. Travel Time Index - Denver
8. Travel Time Index - Colorado Springs
9. Travel Time Index - Congested Rural Corridors
10. Number and Duration of Road Closures
11. Customer Perception of Travel Time Variability
12. The following pages discuss 1) the data required to calculate each of these measures, 2) where to obtain this data, 3) how to calculate the measure given the data, and 4) what assumptions are made in the calculation.

[1] Note: Varying thresholds for identifying congestion are used for Denver, Colorado Springs, and state highways elsewhere. In Denver, the threshold used is a V/C ratio of 0.95 or higher. A V/C ratio of 0.85 or higher is used to identify congestion in Colorado Springs and on state highways elsewhere. The V/C threshold of 0.85 or higher was used for consistency with the Congestion Management System. Travel demand modeling resource constraints at DRCOG at the time this report was prepared precluded the use of 0.85 since 0.95 was already reported in the *Metro Vision 2020 Regional Transportation Plan*.

Person Miles of Travel Under Congested Conditions – Denver

Data Requirements

This measure requires two items of data:

1. *Total person miles of travel in the Denver region.* This information is calculated by DRCOG using their regional travel demand model and is reported on a regular basis.

2. *Percent of vehicle miles of travel under severely congested conditions in the Denver region*. This number is also calculated by DRCOG using their regional travel demand model and is reported regularly. DRCOG defines severe congestion to be a V/C ratio greater than 0.95 for three or more hours in one direction on a roadway segment.

Calculation

The performance measure is calculated by multiplying total person miles of travel by the percent of vehicle miles under severely congested conditions. This calculation assumes that the average vehicle occupancy under congested and un-congested conditions in the Denver region is similar.

Person Miles of Travel Under Congested Conditions – Colorado Springs

Data Requirements

This measure requires five items of data:

1. *AM and PM peak hour V/C ratio for every roadway link in the Colorado Springs travel model.* This information is calculated by PPACG using their regional travel demand model and is updated on a regular basis.

2. *AM and PM peak hour travel volume for every roadway link in the Colorado Springs travel model.* This information is also calculated by PPACG using their regional travel demand model and is updated on a regular basis.

3. *Segment length for every roadway link in the Colorado Springs travel model.* This information is contained in the Colorado Springs regional travel model maintained by PPACG.

4. *Acreage vehicle occupancy in El Paso County.* This information is obtained by aggregating data from statewide accident records at the county level.

5. *Truck trips as a percent of total vehicle trips.* This information is reported regularly by PPACG.

Calculation

The following steps calculate the performance measure:

1. Identify congested roadway links by locating those links with AM or PM peak hour V/C ratio greater than 0.85.

2. For each of the congested links, multiply segment length by peak hour travel volume to obtain congested vehicle miles of travel by segment.

3. Sum congested vehicle miles of travel by segment over all congested links to obtain total congested vehicle miles of travel.

4. Multiply congested vehicle miles of travel by (1 minus truck percent of total vehicle trips) to obtain congested passenger vehicle miles of travel.

5. Multiply congested passenger vehicle miles of travel by average vehicle occupancy to obtain congested person miles of travel.

This calculations assumes that:

1. Average vehicle occupancy under congested and un-congested conditions in the Colorado Springs region is similar.

2. Average vehicle occupancy recorded at accident sites is the same as overall average vehicle occupancy.

3. No off-peak travel has V/C greater than 0.85.

Person Miles of Travel Under Congested Conditions – State Highways Elsewhere

Data Requirements

This measure requires six items of data:

1. Segment length for every state highway link outside the Denver and Colorado Springs regions. [2] This information is collected and reported annually by CDOT Traffic Monitoring.

2. Annual average daily travel (AADT) for every state highway link outside the Denver and Colorado Springs regions. This information is collected and reported annually by CDOT Traffic Monitoring.

3. V/C ratio for every state highway link outside the Denver and Colorado Springs regions. This information is collected and reported annually by CDOT Traffic Monitoring.

4. Truck trips as a percent of total vehicle trips for every state highway link outside the Denver and Colorado Springs regions. This information is collected and reported annually by CDOT Traffic Monitoring.

5. Average vehicle occupancy for all counties outside the Denver and Colorado Springs regions. This information is obtained by aggregating data from statewide accident records at the county level.

[2] That is, every county in Colorado except Denver, Jefferson, Boulder, Douglas, Adams, Arapahoe and El Paso counties.

6. Peak period factor for travel outside Denver and Colorado Springs.

Calculation

The following five steps calculate the performance measure:

1. For each state highway link outside Denver and Colorado Springs, multiply segment length by AADT to obtain vehicle miles of travel by segment.

2. Multiply vehicle miles of travel by (1 minus truck percent of total vehicle trips) to obtain passenger vehicle miles of travel.

3. Multiply passenger vehicle mile of travel by average vehicle occupancy to obtain person miles of travel.

4. Multiply person miles of travel by the peak hour factor to obtain peak period person miles of travel.

5. Sum peak period person mile of travel over all links with V/C greater than 0.85 to obtain person miles of travel under congested conditions.

This calculation assumes that:

1. Average vehicle occupancy recorded at accident sites is the same as overall average vehicle occupancy.
2. Peak period average vehicle occupancy is similar to off-peak vehicle occupancy.
3. The peak period factor is the same of all congested roadways.
4. The peak period factors for all counties outside of Denver and Colorado Springs are similar.
5. If V/C is greater than 0.85, then all travel in the peak period operates under congested conditions.
6. No off-peak travel has V/C greater than 0.85.

Freight Ton-Miles of Travel Under Congested Conditions - Denver

Data Requirements

This measure requires four items of data:

1. *Total vehicle miles of travel in the Denver region.* This information is calculated by DRCOG using their regional travel demand model and is reported on a regular basis.

2. *Commercial trips as a percent of total vehicle trips.* This information is also reported regularly by DRCOG.

3. *Percent of vehicle miles of travel under severely congested conditions in the Denver region.* This number is calculated by DRCOG using their regional travel demand model and is reported

regularly. DRCOG defines severe congestion to be a V/C ratio greater than 0.95 for three or more hours in one direction on a roadway segment.

4. *Statewide average freight per truck.* This information is available from CDOT's Commercial Vehicle Office and is based on vehicle weight data collected at Ports of Entry and Weigh Stations.

Calculation

The following three steps calculate the performance measure:

1. Multiply total vehicle miles of travel by the commercial percent of total vehicle trips to obtain total truck vehicle miles of travel.

2. Multiply total truck vehicle miles of travel by the average freight per truck in tons to obtain total freight ton-miles of travel.

3. Multiply total freight ton-miles of travel by the percent of vehicle miles under congested conditions to obtain freight ton-miles of travel under congested conditions.

This calculation assumes that:

1. The average freight per truck in the Denver region is similar to the average freight per truck statewide.

2. The percentage of passenger vehicle travel and freight vehicle travel under congested conditions in the Denver region is similar.

3. The average freight per truck under congested and un-congested conditions in the Denver region is similar.

Freight Ton-Miles of Travel Under Congested Conditions - Colorado Springs

Data Requirements

This measure requires five items of data:

1. *AM and PM peak hour V/C ratio for every roadway link in the Colorado Springs travel model.* This information is calculated by PPACG using their regional travel demand model and is updated on a regular basis.

2. *AM and PM peak hour travel volume for every roadway link in the Colorado Springs travel model.* This information is also calculated by PPACG using their regional travel demand model and is updated on a regular basis.

3. *Segment length for every roadway link in the Colorado Springs Travel model.* This information is contained in the Colorado Springs regional travel model maintained by PPACG.

4. *Statewide average freight per truck.* This information is available from CDOT's Commercial Vehicle Office and is based on vehicle weight data collected at Ports of Entry and Weight Stations.

6. *Truck trips as a percent of total vehicle trips.* This information is reported regularly by PPACG.

Calculation

The following five steps calculate the performance measure:

1. Identify congested roadway links by locating those links with AM or PM peak hour V/C ratio greater than 0.85.

2. For each of the congested links, multiply segment length by peak hour travel volume to obtain congested vehicle miles of travel by segment.

3. Sum congested vehicle miles of travel by segment over all congested links to obtain total congested vehicle miles of travel.

4. Multiply congested vehicle miles of travel by (1 minus truck percent of total vehicle trips) to obtain congested passenger vehicle miles of travel.

5. Multiply congested passenger vehicle miles of travel by average vehicle occupancy to obtain congested person miles of travel.

This calculation assumes that:

1. The average freight per truck in the Colorado Springs region is similar to the average freight per truck statewide.

2. The average freight per truck under congested and un-congested conditions in the Colorado Springs region is similar.

3. No off-peak travel has V/C than 0.85.

Freight Ton-Miles of Travel Under Congested Conditions - State Highways Elsewhere

Data Requirements

This measure requires six items of data:

1. Segment length for every state highway link outside the Denver and Colorado Springs regions. [3] This information is collected and reported annually by CDOT Traffic Monitoring.

2. Annual average daily travel (AADT) for every state highway link outside the Denver and Colorado Springs regions. This information is collected and reported annually by CDOT Traffic Monitoring.

[3] That is, every county in Colorado except Denver, Jefferson, Boulder, Douglas, Adams, Arapaho and El Paso counties.

3. V/C ratio for every state highway link outside the Denver and Colorado Springs regions. This information is collected and reported annually by CDOT Traffic Monitoring.

4. Truck trips as a percent of total vehicle trips for every state highway link outside the Denver and Colorado Springs regions. This information is collected and reported annually by CDOT Traffic Monitoring.

5. Average vehicle occupancy for all counties outside the Denver and Colorado Springs regions. This information is obtained by aggregating data from statewide accident records at the county level.

6. Peak period factor for travel outside Denver and Colorado Springs.

Calculation

The following five steps calculate the performance measure:

1. For each state highway link outside Denver and Colorado Springs, multiply segment length by AADT to obtain vehicle miles of travel by segment.

2. Multiply vehicle miles of travel by the truck percent of total vehicle trips to obtain freight ton-miles of travel.

3. Multiply truck vehicle miles of travel by the average freight per truck in tons to obtain freight ton-miles of travel.

4. Multiply freight ton-miles of travel by the peak hour factor to obtain peak period freight ton-miles of travel.

5. Sum peak period freight ton-miles of travel over all links with V/C greater than 0.85 to obtain freight ton-miles of travel under congested conditions.

This calculation assumes that:

1. Average freight per truck is similar in all counties outside of Denver and Colorado Springs.

2. Peak period freight per truck is similar to off-peak freight per truck.

3. The peak period factor is the same for all congested roadways.

4. The peak period factors for all counties outside of Denver and Colorado Springs are similar.

5. The peak period factor for truck travel and passenger travel is similar.

6. If V/C is greater than 0.85, than all travel in the peak period operates under congested conditions.

7. No off-peak travel has V/C greater than 0.85.

Travel Time Index - Denver

Data Requirements

This measure requires three items of data:

1. Peak period and off-peak auto travel time for selected origin-destination pairs. This information needs to be extracted from the travel demand model outputs generated by DRCOG. The auto travel time should be based on using no-carpool lanes.

2. Peak period and off-peak transit travel time for selected origin-destination pairs. This information is developed manually from published transit schedules. Transit travel time includes transfer time, but not time at the originating transit stop. The fastest of light-rail, express bus and regular bus should be used.

3. The total daily person-trips by all modes for selected origin-destination pairs. This information needs to be extracted from the travel demand model outputs generated by DRCOG. Generating this information will first require a precise definition of what specific set of traffic analysis zones (TAZs) represent each of the selected origins of destinations.

Calculation

For a given mode and time period, sum the product of travel item and total daily person-trips over all of the selected origin-destination pairs. This produces a K-value for this mode and time period. Repeat this calculation for all modes and time periods to arrive at K-values for auto and transit for both peak and off-peak periods.

Calculate the Travel Time Index for each mode and time period by dividing each of the K-values by the auto, peak period K-value and multiply by 100. The resulting auto, peak period Travel Time Index should be 100. All other Travel Time Indices are compared relative to this base value.

Travel Time Index - Colorado Springs

Data Requirements

The data requirements for Colorado Springs are similar to that for the Denver Travel Time Index.

Calculation

The calculation is similar to that for the Denver Travel Time Index.

Travel Time Index - Congested Rural Corridors

This measure only takes three particularly congested rural corridors into account:

1. I-70 from Vail to outside Denver (milepost 174 to 247 at Clear Creek/Jefferson county line).

2. SR-82 from Glenwood Springs urban limit to Aspen urban limit (milepost 4 to 40)

3. US-40 from Craig urban limit to just outside Steamboat Springs (milepost 93 to 129)

Data Requirements

This measure requires five items of data for each of the highway links making up the above three corridors. All of this information is collected and reported annually by CDOT Traffic Monitoring.

1. Segment Length.
2. Annual average daily travel (AADT).
3. V/C ratio.
4. Speed limit.
5. Roadway functional class.

Calculation

The following eight steps calculate the performance measure:

1. Define the Peak Period Auto Travel Time Index to be 100.
2. Set the free-flow speed on highway link equal to the speed limit.
3. Use one of the following formulas to calculate the speed under congested conditions. These formulas are best fits to the 1994 Highway Capacity Manual speed-flow curves.

   Congested speed = Free-flow speed / $[1+ 0.161 (V/C)^8]$ for rural interstates
   Congested speed = Free-flow speed / $[1+2.08 (V/C)^6]$ for other principal rural arterials
   Congested speed = Free-flow speed / $[1+2.08 (V/C)^6]$ for minor rural arterials
   Congested speed = Free-flow speed / $[1+2.08 (V/C)^6]$ for major rural collectors
   Congested speed = Free-flow speed / $[1+2.08 (V/C)^6]$ for minor rural collectors
   Congested speed = Free-flow speed / $[1+2.08 (V/C)^6]$ for local rural roads
   Congested speed = Free-flow speed / $[1+0.226 (V/C)^{10}]$ for urban freeways
   Congested speed = Free-flow speed / $[1+2 (V/C)^{10}]$ for other principal urban arterials
   Congested speed = Free-flow speed / $[1+2 (V/C)^{10}]$ for minor urban arterials
   Congested speed = Free-flow speed / $[1+2 (V/C)^{10}]$ for urban collectors

4. Divide segment length by free-flow speed to obtain free-flow travel time.
5. Divide segment length by congested speed to obtain congested travel time.
6. Sum the product of free-flow travel time and AADT over all highway links to obtain the free-flow K-value.
7. Sum the product of congested travel time and AADT over all highway links to obtain the congested K-value.
8. Divide the free-flow K-value by the congested K-value to obtain the Off-Peak Auto Travel Time Index.

Number and Duration of Road Closures

Data Requirements

This measure requires information on when road closures occur, when roads are reopened, and why closures happen. This data is obtained from each individual CDOT Transportation Region since there is no centralized office or database to track road closures statewide. Most regions keep this information in a notebook with road closure sheets on individual road closures. At the present time, the only roadways for which a complete record of closures is kept are I-70 and I-25.

Calculation

Once road closure data is obtained from each Region, each closure is classified by cause: weather, incident, incident involving commercial vehicles, or some other factor. The number of road closures and their duration are totaled by the cause of closure to develop the performance measures.

Customer Perception of Travel Time Variability

The information for this performance measure came from a one-time study done in 1997 (the CDOT Near-Term Investment Program Customer Survey). CDOT has no plan at this time to repeat this survey. A regular surveying process will need to be put in place to track this performance measure over time.

APPENDIX C
Required Sample Size by Confidence Interval

The following table presents the required sample size from a range of population sizes at the 90%, 95%, and 99% confidence level (CL) with a margin of error of 10%:

	Required Sample Size		
Population	**90% CL**	**95% CL**	**99% CL**
500	60	81	125
1,000	64	88	143
1,500	65	91	150
2,000	66	92	154
2,500	66	93	156
3,000	67	94	158
3,500	67	94	159
4,000	67	94	160
4,500	67	95	161
5,000	67	95	161
5,500	67	95	162
6,000	67	95	162
6,500	67	95	162
7,000	68	95	163
7,500	68	95	163
8,000	68	95	163
8,500	68	95	163
9,000	68	96	163
9,500	68	96	164
10,000	68	96	164

NOTE: The above sample sizes by confidence level and population size were obtained from the Sample Size Calculator provided on the Arizona Plan Site web page located at http://www.azplansite.com/samplesize.htm. The calculator is a product of the Sunregion Associates & Research Advisory Services group.

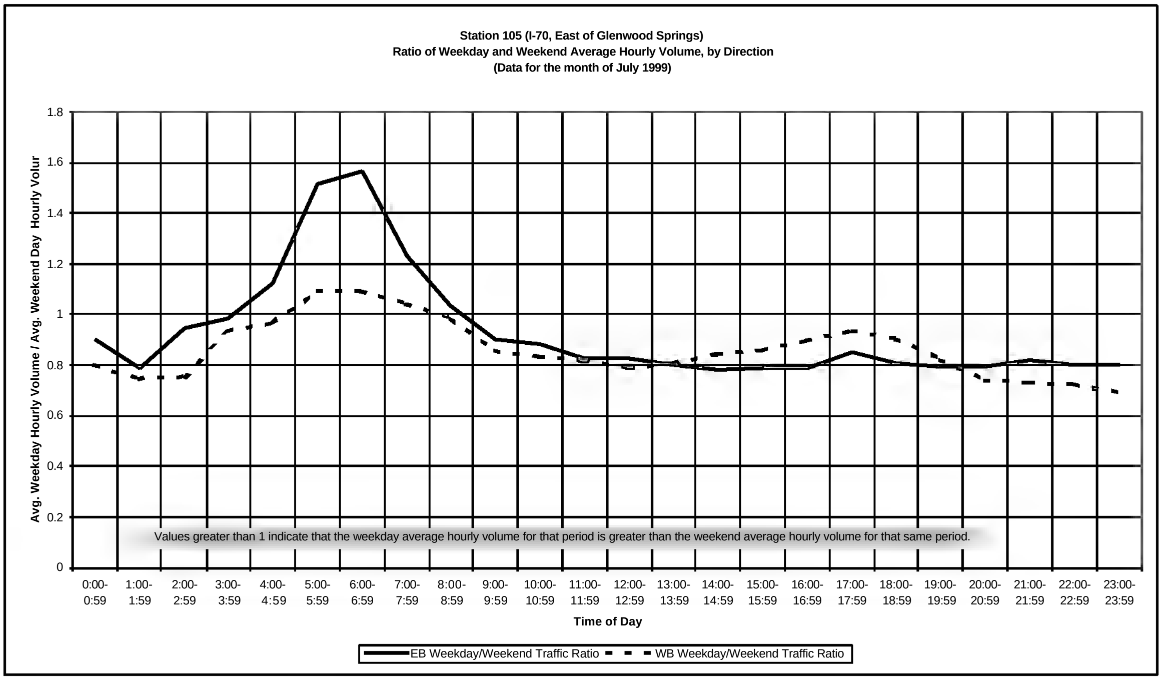
APPENDIX D
ATR Station Locations by Seasonal Group

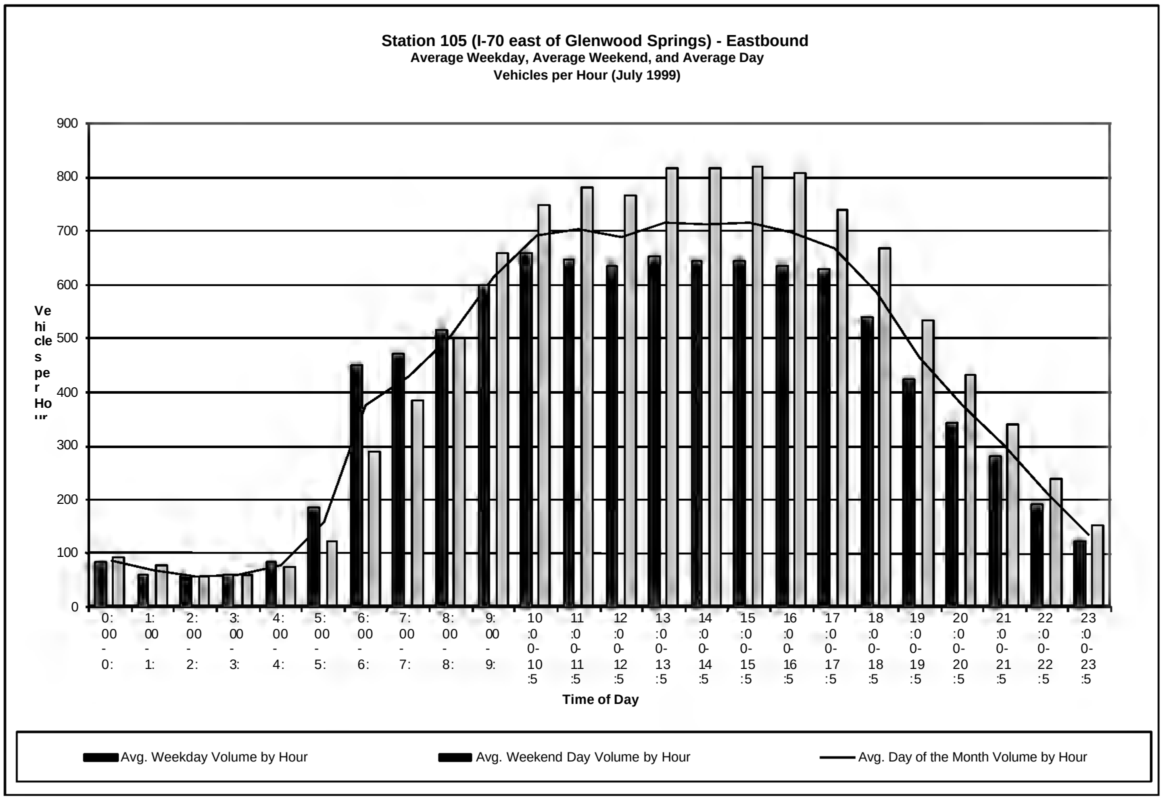
Seasonal Group	ATR Station	Hwy Route	Hwy Ref. Point	Station Location	Functional Class
Group 1 – Interstate Rural					
1	101	025A	10.7	ON I-25 S/O STARKVILLE INTERCHANGE, ATR 101	Interstate-Rural
1	102	025A	104.0	ON I-25 N/O EDEN INTERCHANGE, ATR 102 (SHRP)	Interstate-Rural
1	108	070A	310.4	ON I-70 W/O SH 36, BYERS ATR 108	Interstate-Rural
1	112	070A	74.2	ON I-70 W/O PARACHUTE INTERCHANGE, (SHRP 112),MP 74.26	Interstate-Rural
1	113	070A	97.1	ON I-70 W/O SH 70 SILT SPUR, (SHRP 113), MP 97.10	Interstate-Rural
1	115	070A	291.2	ON I-70 W/O AIR PARK RD, (SHRP 115)	Interstate-Rural
1	153	025A	298.7	ON I-25 AT COLO-WYOMING STATE LINE, WYO ATR 153	Interstate-Rural
1	105	070A	118.0	ON I-70 W/O NO NAME INTERCHANGE, ATR 105	Interstate-Urban
1	118	076A	19.7	ON I-76 NE/O 136TH AVE (SHRP 118)	Interstate-Urban
				TOTAL	**9**
Group 2 – Other Rural					
2	503	006G	283.3	ON SH 6, 6TH AVE W/O SH 88, FEDERAL BLVD, ATR 503	Freeway-Urban
2	302	067E	126.5	ON SH 67 SW/O SH 105, SEDALIA, ATR 302	Major Coll-Rural
2	202	010A	0.5	ON SH 10 0.5 MI E/O I-25, E/O WALSENBURG, ATR 202	Minor Art-Rural
2	204	014C	152.0	ON SH 14 APPROX 1.0 MI W/O SH 85, AULT, ATR 204	Minor Art-Rural
2	213	071D	173.1	ON SH 71 1.0 MI S/O E JCT SH 34, E/O BRUSH, ATR 213	Minor Art-Rural
2	215	085C	293.0	ON SH 85 5.0 MI N/O NUNN, ATR 215	Minor Art-Rural
2	235	064A	16.6	ON SH 64 @ MP 16.60, W/O RANGELY, ATR 235	Minor Art-Rural
2	251	040H	486.7	ON SH 40 AT COLO-KANSAS STATE LINE, KANSAS ATR 251	Minor Art-Rural
2	304	092A	7.0	ON SH 92 E/O CO RD 22.00, AUSTIN, ATR 304	Minor Art-Rural
2	305	096B	103.5	ON SH 96 2.0 MI W/O S JCT SH 71, ORDWAY, ATR 305	Minor Art-Rural
2	307	067C	70.1	ON SH 67 S/O SH 24, DIVIDE, ATR 307	Minor Art-Rural
2	314	131B	64.2	ON SH 131 N/O CO RD 18, ATR 314	Minor Art-Rural
2	660	014C	234.1	ON SH 14 0.3 MI W/O CO RD 35, (SHRP 660)	Minor Art-Rural
2	206	034B	257.0	ON SH 34 AT ECL LAIRD, ATR 206	Other Pri Art-Rural
2	209	040A	97.4	ON SH 40 E/O CO RD 225, AT ECL CRAIG, ATR 209	Other Pri Art-Rural
2	212	050B	382.8	ON SH 50 E/O LA JUNTA @ THOMPSON ARROYO, ATR 212	Other Pri Art-Rural
2	217	160A	101.3	ON SH 160 W/O W JCT SH 160 BAYFIELD BUS RT, ATR 217	Other Pri Art-Rural
2	218	160A	219.1	ON SH 160 E/O CO RD 3E, ZINZER, ATR 218	Other Pri Art-Rural
2	221	385C	189.3	ON SH 385 @ NCL BURLINGTON, N/O RR TRACKS, ATR 221	Other Pri Art-Rural
2	227	160A	33.0	ON SH 160 S/O CO RD D, ATR 227	Other Pri Art-Rural
2	228	024A	279.0	ON SH 24 1.0 MI E/O SH 67, DIVIDE ATR 228	Other Pri Art-Rural
2	229	024A	289.3	ON SH 24 0.2 MI SE/O UTE PASS AVE, GREEN MTN FALLS	Other Pri Art-Rural
2	231	040A	136.0	ON SH 40 N/O SH 131, S/O STEAMBOAT SPGS, ATR 231	Other Pri Art-Rural
2	242	050A	45.0	ON SH 50 E/O KANNAH CREEK RD ATR 242	Other Pri Art-Rural
2	250	050B	467.5	ON SH 50 AT COLO-KANSAS STATE LINE, KANSAS ATR 250	Other Pri Art-Rural
2	254	287C	385.2	ON SH 287 AT COLORADO-WYO STATE LINE, WYO ATR 254	Other Pri Art-Rural
2	255	666B	69.6	ON SH 666 AT COLORADO-UTAH STATE LINE, UTAH ATR 255	Other Pri Art-Rural
				TOTAL	**27**
Group 3 – Recreational					
3	104	070A	10.0	ON I-70 W/O MACK INTERCHANGE, ATR 104	Interstate-Rural
3	109	070A	438.5	ON I-70 NE/O SH 70 BURLINGTON SPUR, ATR 109	Interstate-Rural
3	110	076A	180.8	ON I-76 NE/O SH 385, JULESBURG, ATR 110	Interstate-Rural
3	201	009D	103.9	ON SH 9 0.2 MI N/O CO RD 1900, HAMILTON CREEK RD	Minor Art-Rural
3	203	013B	127.1	ON SH 13 AT COLO-WYOMING STATE LINE, ATR 203	Minor Art-Rural
3	312	119A	21.4	ON SH 119 SW/O CO RD CH1, N/O ROLLINSVILLE, ATR 312	Minor Art-Rural
3	208	040A	2.2	ON SH 40 AT UTAH-COLORADO STATE LINE, ATR 208	Other Pri Art-Rural
3	211	050A	164.7	ON SH 50 0.8 MI W/O SH 114, ATR 211	Other Pri Art-Rural
3	219	285C	147.9	ON SH 285 S/O SH 24, JOHNSON VILLAGE, ATR 219	Other Pri Art-Rural
3	230	040A	74.9	ON SH 40 2.5 MI NE/O CO RD 14 (SHRP 230)	Other Pri Art-Rural
				TOTAL	**10**
Group 4 – High Recreational					
4	216	125A	1.0	ON SH 125 N/O SH 40, W/O GRANBY, ATR 216	Minor Art-Rural
4	205	034A	65.0	ON SH 34 E/O CO RD 63, ESTES PARK, ATR 205	Other Pri Art-Rural
4	244	036B	101.7	ON SH 36 E/O MALL RD	Other Pri Art-Rural

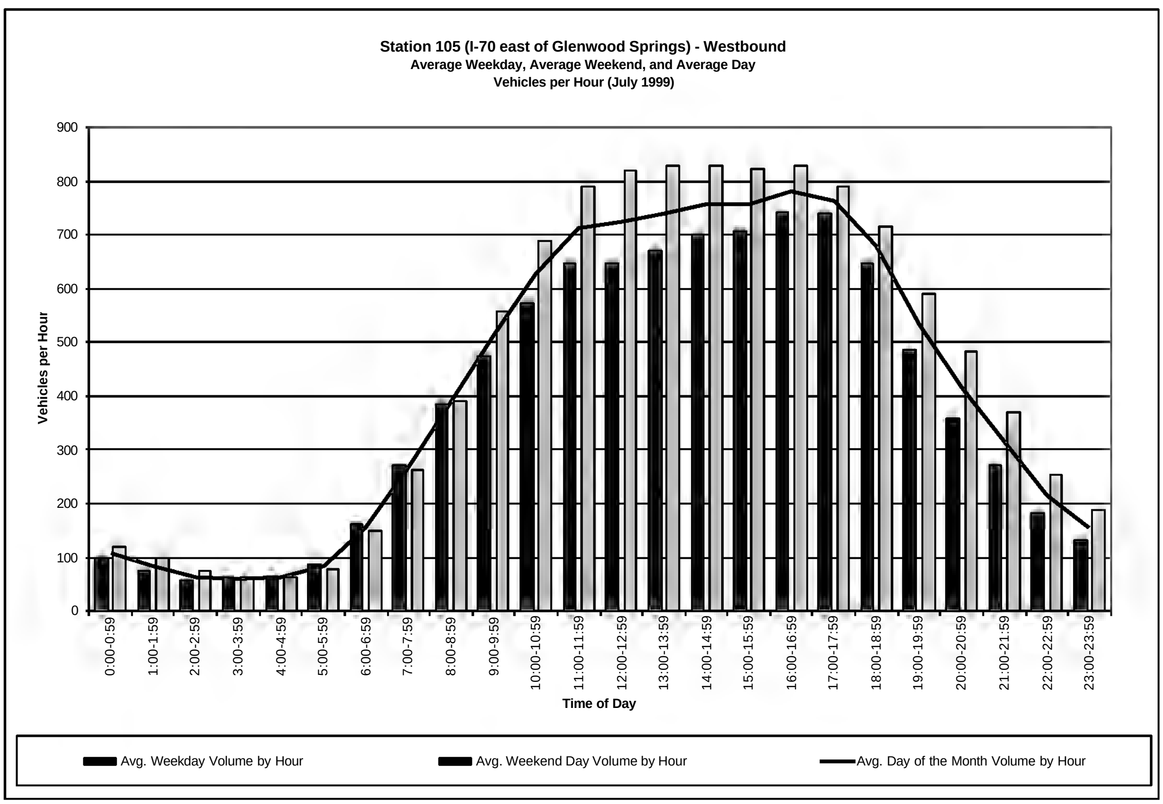
Seasonal Group	ATR Station	Hwy Route	Hwy Ref. Point	Station Location	Functional Class
				TOTAL	**3**
Group 5 – Interstate Urban					
5	520	025A	142.1	ON I-25 N/O BIJOU ST INTERCHANGE, ATR 520	Freeway-Urban
5	103	025A	229.9	ON I-25 N/O SH 7 INTERCHANGE, ATR 103	Interstate-Rural
5	111	025A	257.0	ON I-25 S/O SH 34 INTERCHANGE (SHRP 111)	Interstate-Rural
5	114	070A	288.6	ON I-70 NW/O SH 40, COLFAX AVE, E/O AURORA, (SHRP 114)	Interstate-Urban
5	124	025A	180.8	ON I-25 S/O SOUTH CASTLE ROCK INTERCHANGE	Interstate-Urban
5	125	025A	183.2	ON I-25 N/O SH 85 INTERCHANGE, CASTLE ROCK, ATR 125	Interstate-Urban
5	501	025A	208.5	ON I-25 S/O SH 6, 6TH AVE INTERCHANGE, ATR 501	Interstate-Urban
5	507	270A	0.4	ON I-270 SE/O YORK ST, ATR 507	Interstate-Urban
5	510	070A	270.6	ON I-70 E/O SH 95, SHERIDAN BLVD, ATR 510	Interstate-Urban
				TOTAL	**9**
Group 6 – Other Urban					
6	504	036B	149.0	ON SH 36 SE/O SH 121, SE/O BROOMFIELD, ATR 504	Freeway-Urban
6	311	119A	0.1	ON SH 119 N/O SH 119 LOG D, N/O WYE, ATR 311	Minor Art-Rural
6	236	082A	26.6	ON SH 82 NW/O CO RDS 11 & 16, SNOWMASS, ATR 236	Other Pri Art-Rural
6	214	082A	2.4	ON SH 82 0.1 MI S/O BLAKE AVE, GLENWOOD SPGS, ATR 214	Other Pri Art-Urban
6	604	002A	5.8	ON SH 2, COLO BLVD S/O SH 40, COLFAX AVE, ATR 604	Other Pri Art-Urban
6	609	044A	2.3	ON SH 44, 104TH AVE W/O BRIGHTON RD ATR 609	Other Pri Art-Urban
				TOTAL	**6**
Group 7 – Special Case					
7	106	070A	213.6	ON I-70 AT EISENHOWER TUNNEL, ATR 106	Interstate-Rural
7	107	070A	253.7	ON I-70 E/O GENESEE MTN INTERCHANGE, ATR 107	Interstate-Rural
7	119	070A	195.2	ON I-70 W/O SH 91 ATR 119	Interstate-Rural
7	120	070A	241.1	ON I-70 AT IDAHO SPRINGS TWIN TUNNELS	Interstate-Rural
7	126	070A	173.1	ON I-70 W/O WEST VAIL INTERCHANGE	Interstate-Rural
7	308	135A	3.4	ON SH 135 NE/O OHIO CK RD, ATR 308	Minor Art-Rural
7	223	040A	249.4	ON SH 40 E/O HENDERSON MINE RD, ATR 223	Other Pri Art-Rural
7	240	009C	92.0	ON SH 9 0.7 MI S/O SWAN MTN RD	Other Pri Art-Rural
				TOTAL	**8**

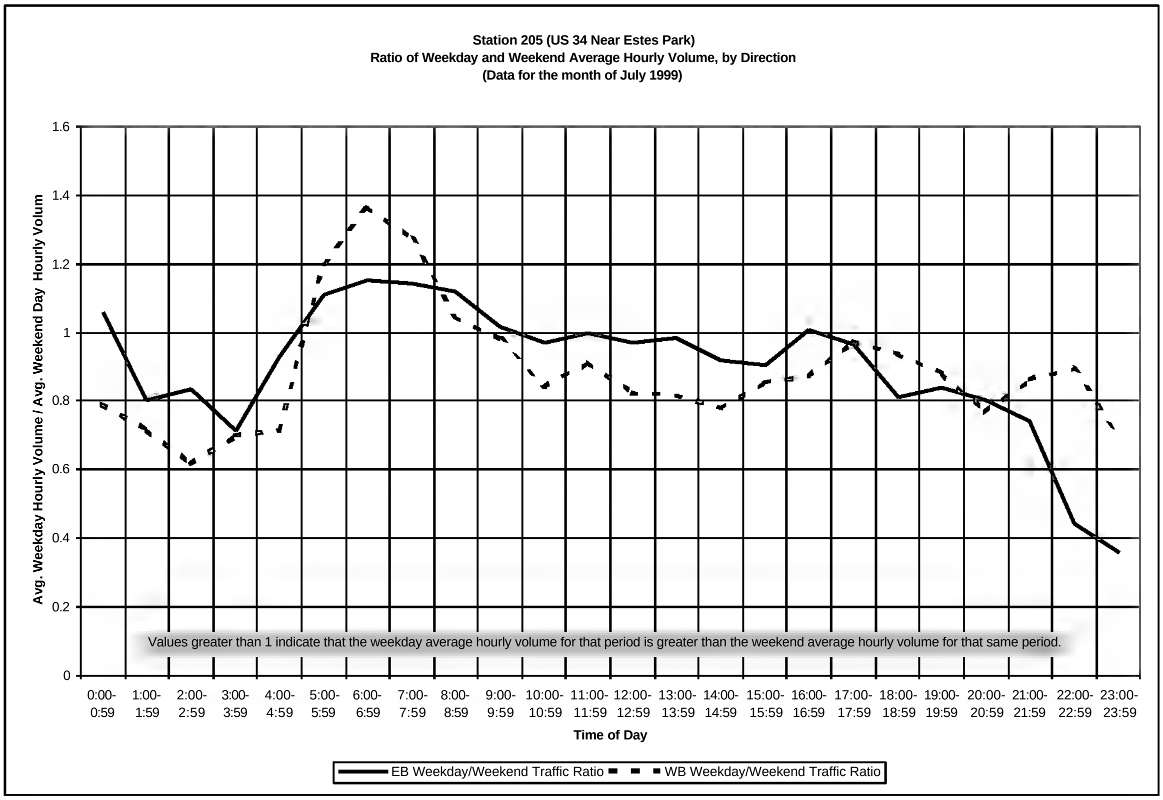
APPENDIX E
Sample ATR Profiles

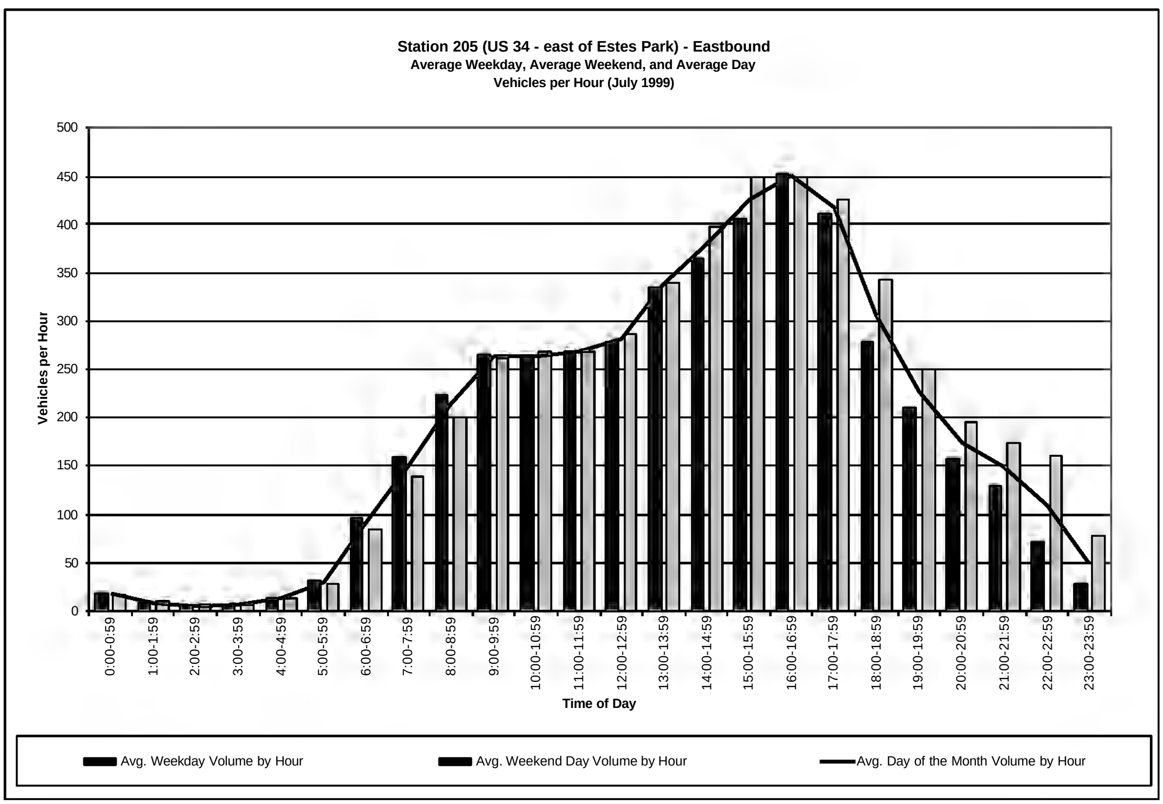
The following chart groups consist of three charts for each ATR station used in the analysis for AADT, Directional Distribution, and Highest Hourly Volume. The first chart in each series graphically illustrates the difference between the weekday/weekend ration for each station by direction by hour of the day for the month of July 1999. A portion of the chart where the weekday/weekend ratio exceeds 1.0 indicates the time of day when the average hourly weekday volume exceeds the average hourly weekend volume. Similarly, where the directional lines fall below 1.0 the average weekend hourly volume is greater than the average hourly weekday volume. The next two charts for each ATR station graphically illustrate the average weekday, average weekend, and average day hourly volume for the month of July 1999.

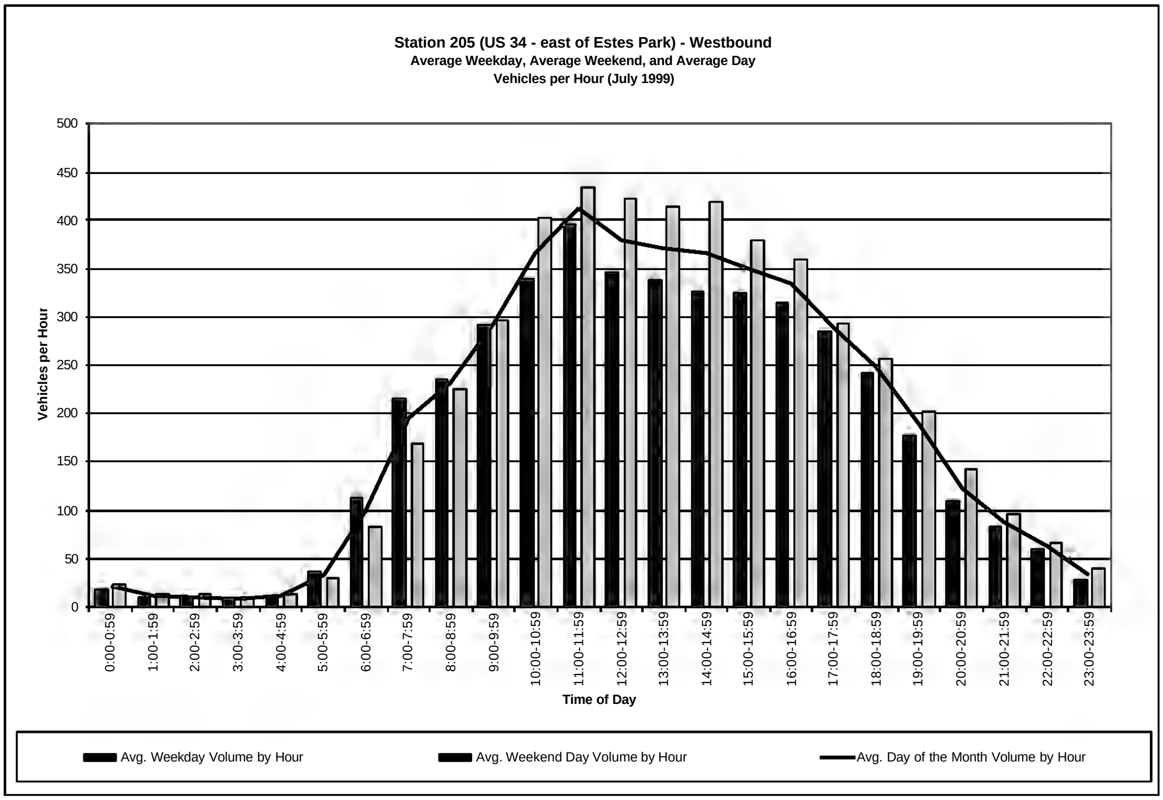


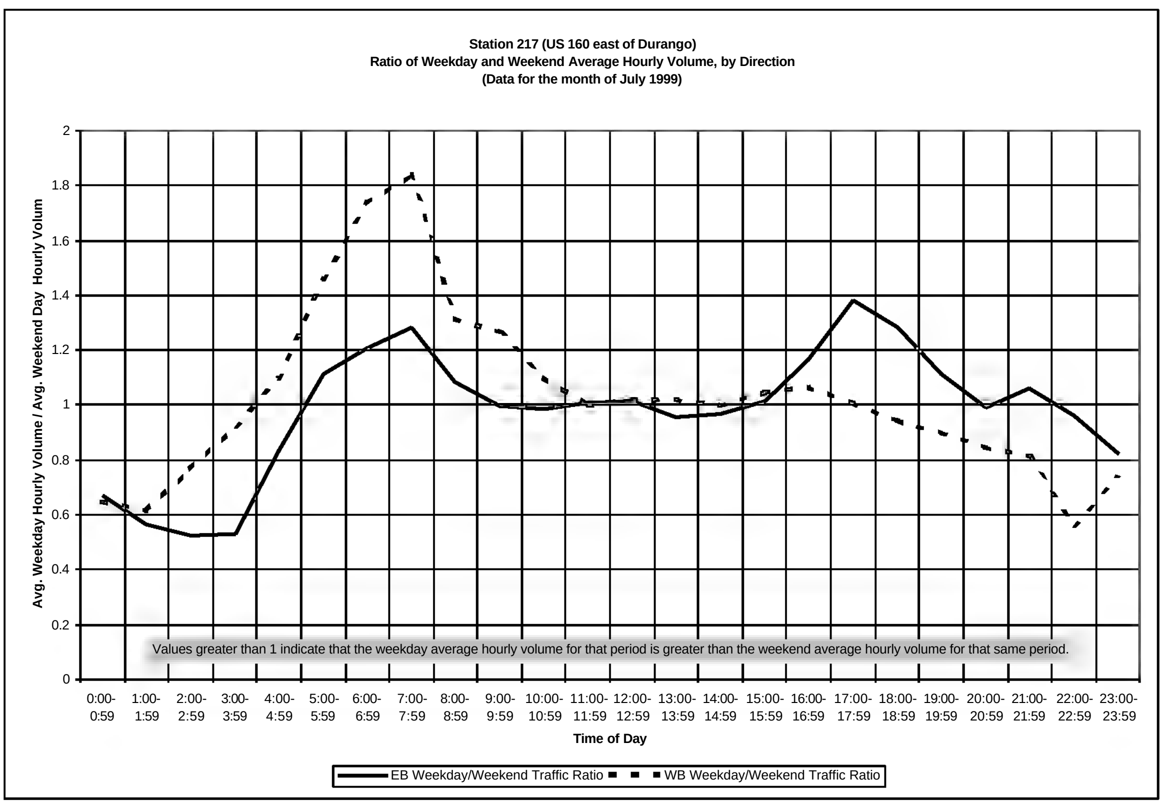

Station 105 (I-70 east of Glenwood Springs) - Eastbound
Average Weekday, Average Weekend, and Average Day
Vehicles per Hour (July 1999)
Vehicles per Hour
Time of Day
Avg. Weekday Volume by Hour
Avg. Weekend Day Volume by Hour
Avg. Day of the Month Volume by Hour

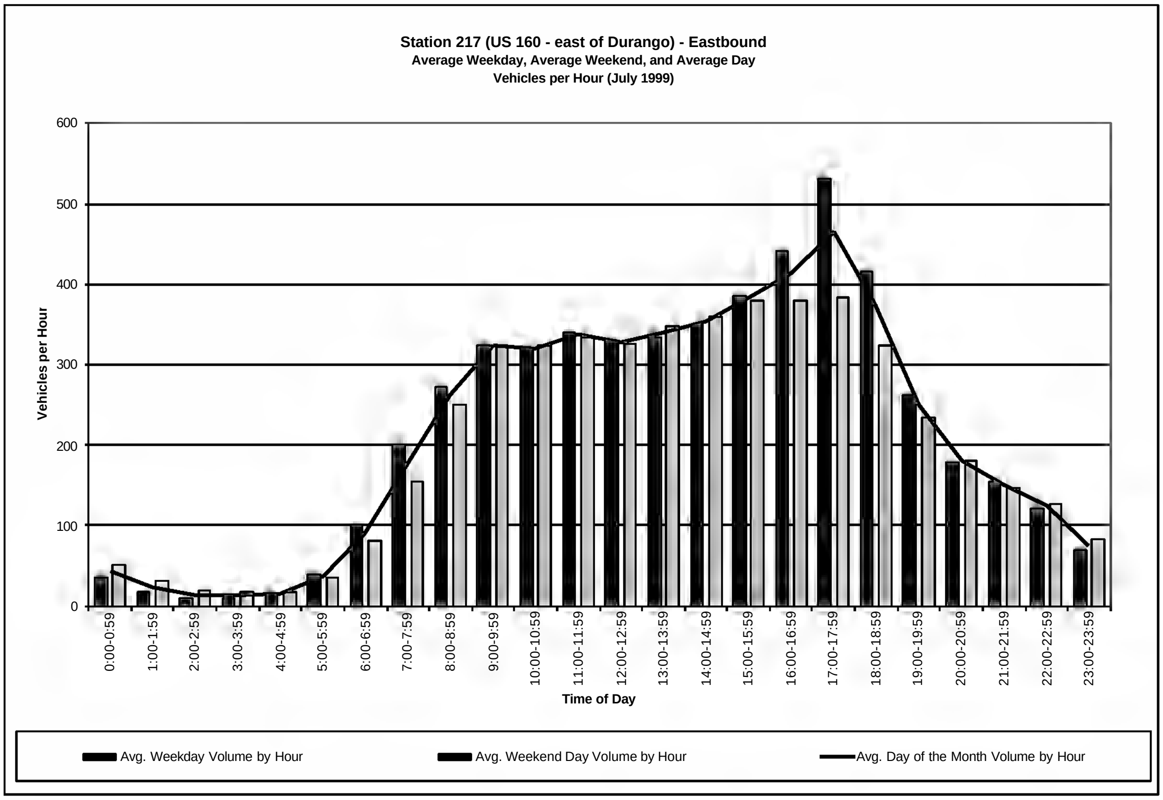

Station 105 (I-70 east of Glenwood Springs) - Westbound
Average Weekday, Average Weekend, and Average Day
Vehicles per Hour (July 1999)
Vehicles per Hour
Time of Day
Avg. Weekday Volume by Hour
Avg. Weekend Day Volume by Hour
Avg. Day of the Month Volume by Hour

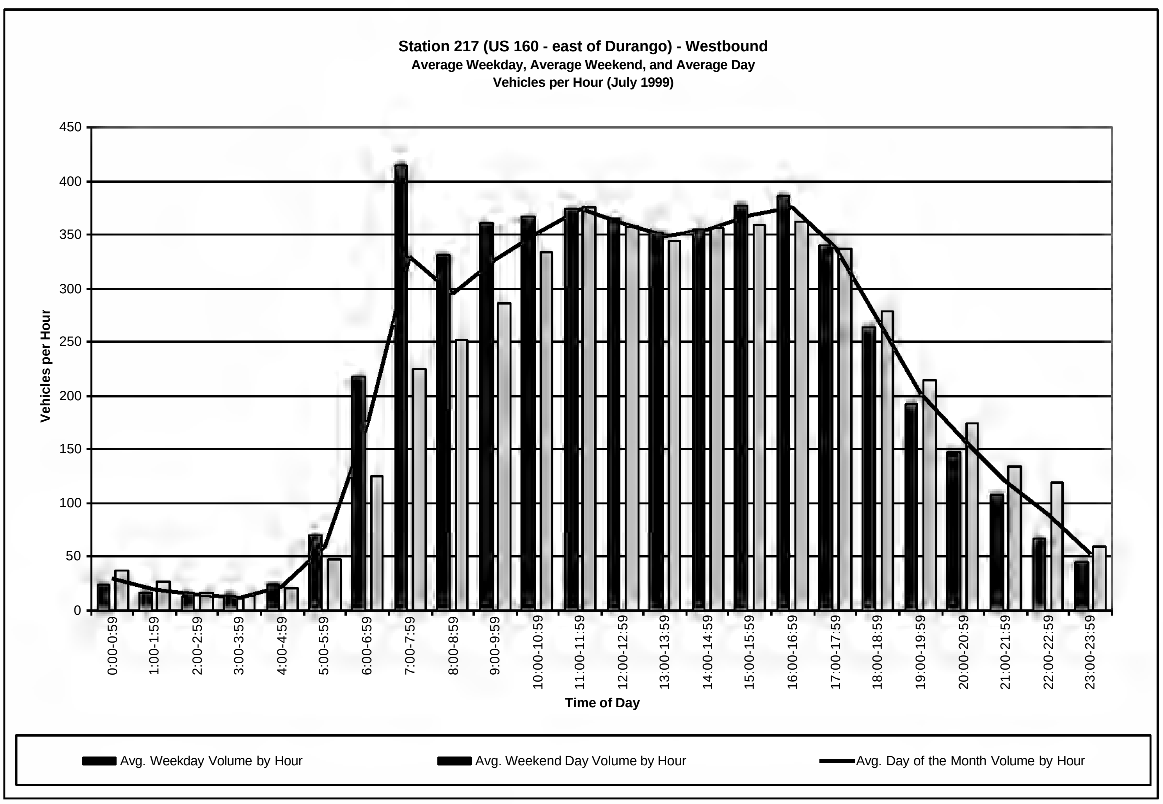

Station 205 (US 34 Near Estes Park)
Ratio of Weekday and Weekend Average Hourly Volume, by Direction
(Data for the month of July 1999)
Avg. Weekday Hourly Volume / Avg. Weekend Day Hourly Volum
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Values greater than 1 indicate that the weekday average hourly volume for that period is greater than the weekend average hourly volume for that same period.
0:00-0:59
1:00-1:59
2:00-2:59
3:00-3:59
4:00-4:59
5:00-5:59
6:00-6:59
7:00-7:59
8:00-8:59
9:00-9:59
10:00-10:59
11:00-11:59
12:00-12:59
13:00-13:59
14:00-14:59
15:00-15:59
16:00-16:59
17:00-17:59
18:00-18:59
19:00-19:59
20:00-20:59
21:00-21:59
22:00-22:59
23:00-23:59
Time of Day
EB Weekday/Weekend Traffic Ratio
WB Weekday/Weekend Traffic Ratio

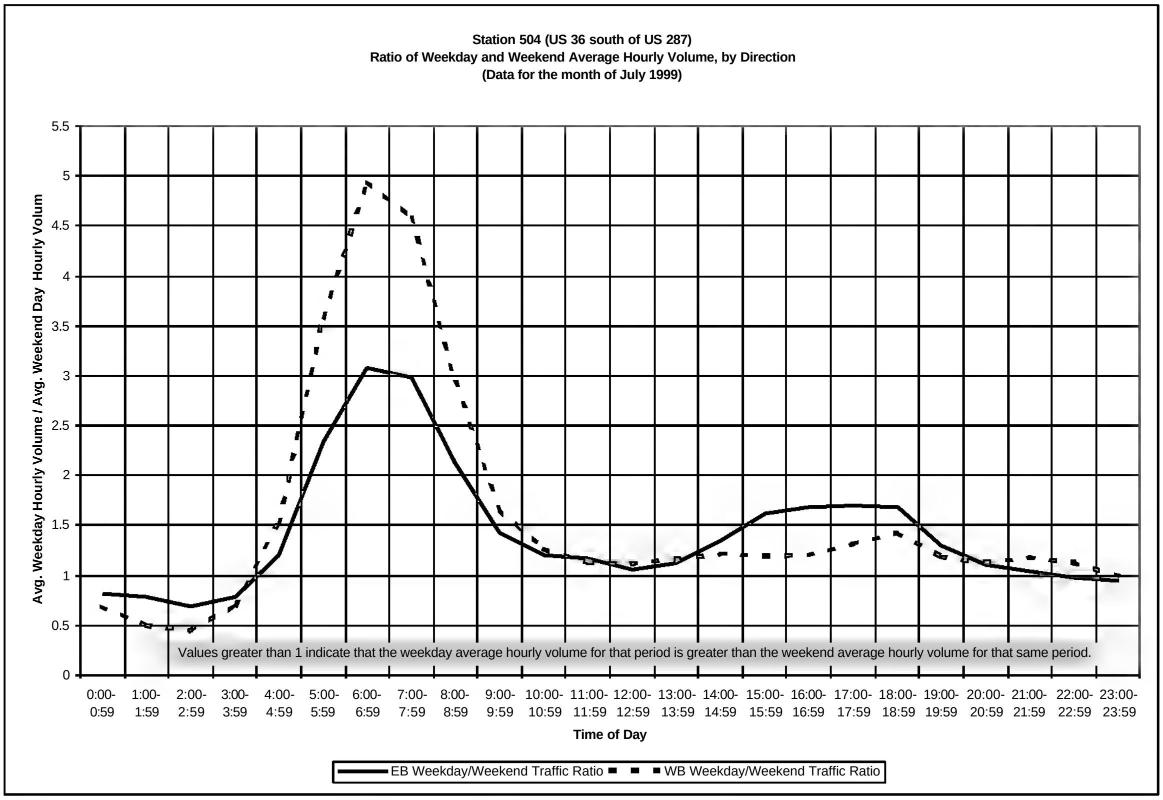

Station 205 (US 34 - east of Estes Park) - Eastbound
Average Weekday, Average Weekend, and Average Day
Vehicles per Hour (July 1999)
Vehicles per Hour
500
450
400
350
300
250
200
150
100
50
0
0:00-0:59
1:00-1:59
2:00-2:59
3:00-3:59
4:00-4:59
5:00-5:59
6:00-6:59
7:00-7:59
8:00-8:59
9:00-9:59
10:00-10:59
11:00-11:59
12:00-12:59
13:00-13:59
14:00-14:59
15:00-15:59
16:00-16:59
17:00-17:59
18:00-18:59
19:00-19:59
20:00-20:59
21:00-21:59
22:00-22:59
23:00-23:59
Time of Day
Avg. Weekday Volume by Hour
Avg. Weekend Day Volume by Hour
Avg. Day of the Month Volume by Hour

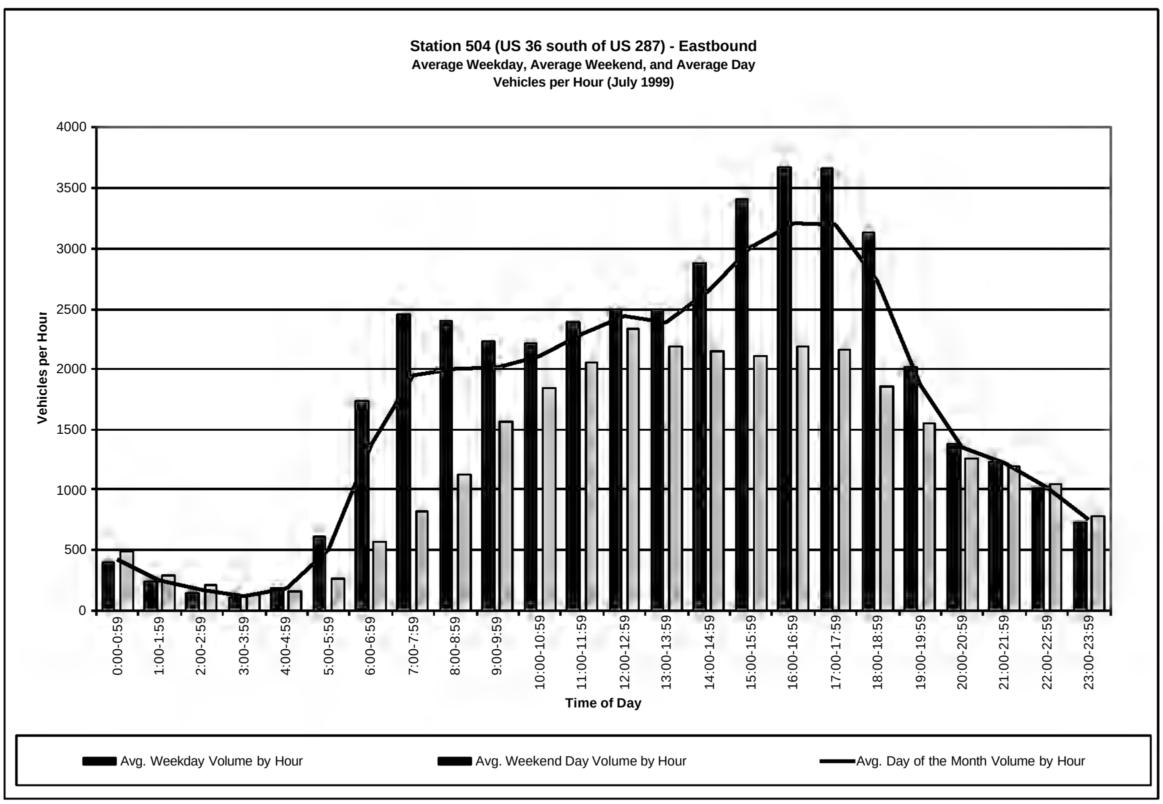

Station 205 (US 34 - east of Estes Park) - Westbound
Average Weekday, Average Weekend, and Average Day
Vehicles per Hour (July 1999)
Vehicles per Hour
Time of Day
Avg. Weekday Volume by Hour
Avg. Weekend Day Volume by Hour
Avg. Day of the Month Volume by Hour

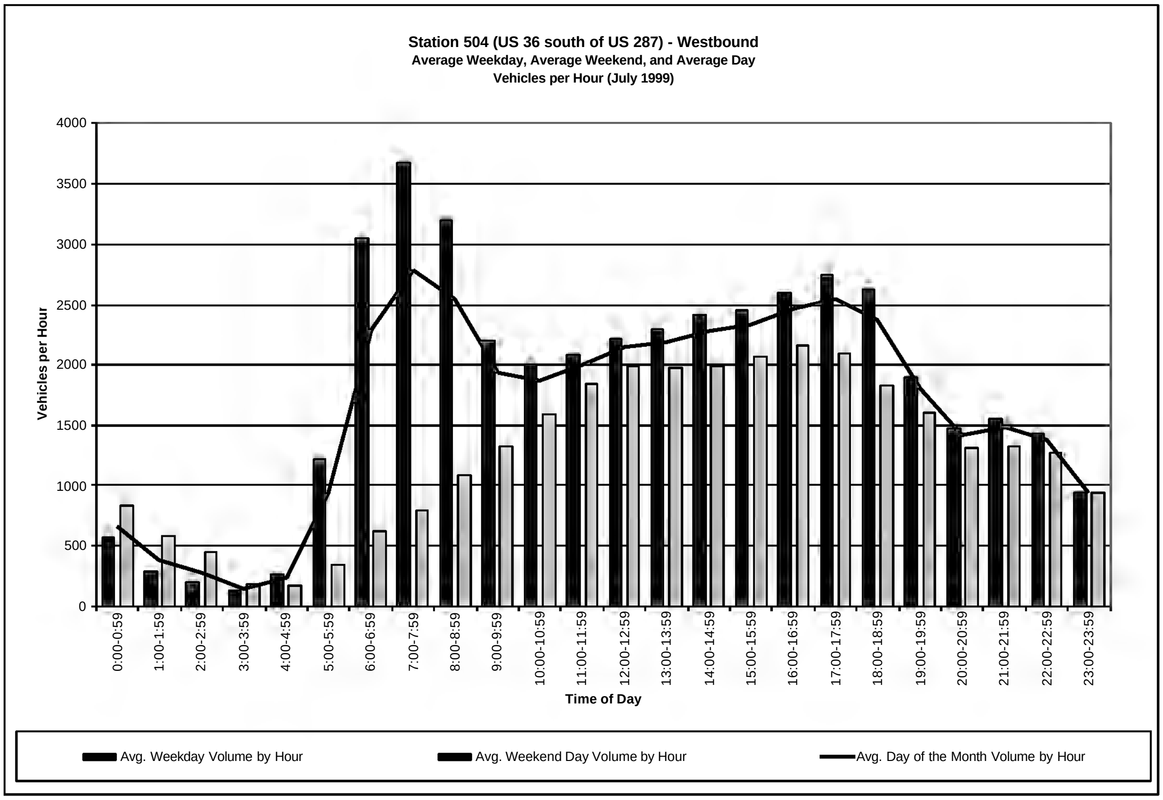

Station 217 (US 160 east of Durango)
Ratio of Weekday and Weekend Average Hourly Volume, by Direction
(Data for the month of July 1999)
Avg. Weekday Hourly Volume / Avg. Weekend Day Hourly Volum
Values greater than 1 indicate that the weekday average hourly volume for that period is greater than the weekend average hourly volume for that same period.
Time of Day
EB Weekday/Weekend Traffic Ratio
WB Weekday/Weekend Traffic Ratio

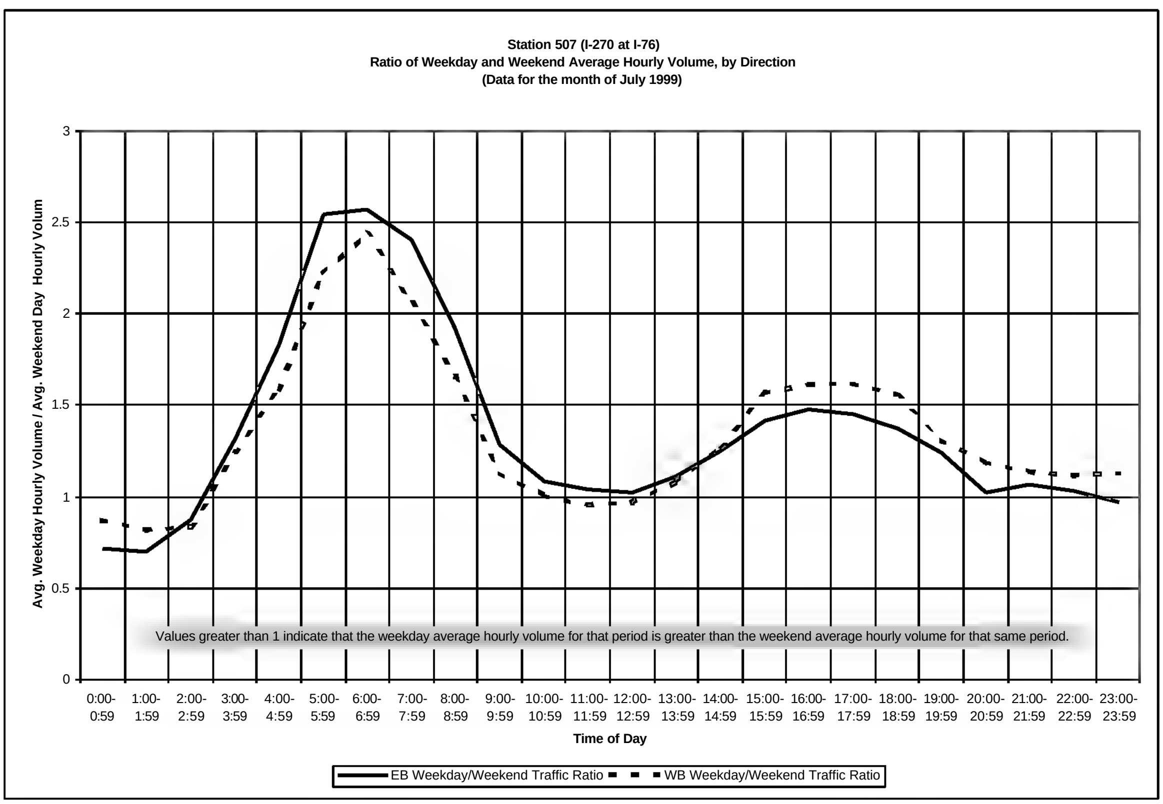

Station 217 (US 160 - east of Durango) - Eastbound
Average Weekday, Average Weekend, and Average Day
Vehicles per Hour (July 1999)
Vehicles per Hour
0
100
200
300
400
500
600
0:00-0:59
1:00-1:59
2:00-2:59
3:00-3:59
4:00-4:59
5:00-5:59
6:00-6:59
7:00-7:59
8:00-8:59
9:00-9:59
10:00-10:59
11:00-11:59
12:00-12:59
13:00-13:59
14:00-14:59
15:00-15:59
16:00-16:59
17:00-17:59
18:00-18:59
19:00-19:59
20:00-20:59
21:00-21:59
22:00-22:59
23:00-23:59
Time of Day
Avg. Weekday Volume by Hour
Avg. Weekend Day Volume by Hour
Avg. Day of the Month Volume by Hour

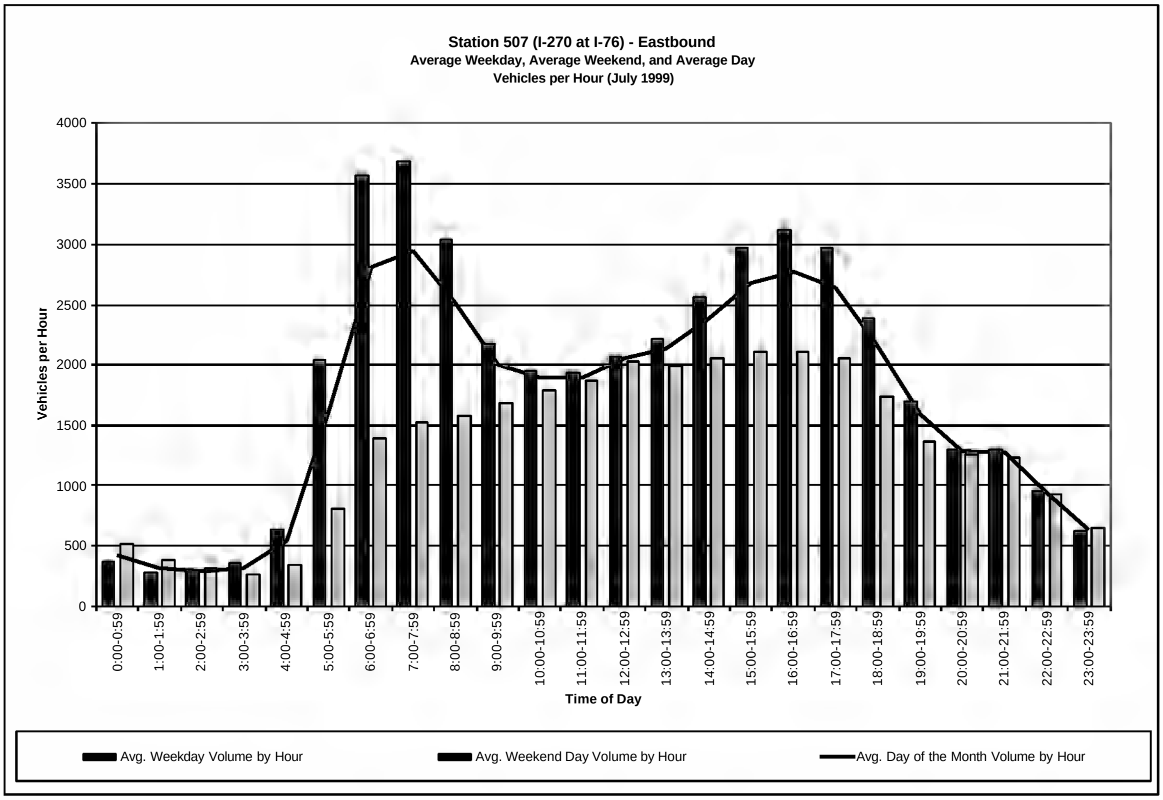

Station 217 (US 160 - east of Durango) - Westbound
Average Weekday, Average Weekend, and Average Day
Vehicles per Hour (July 1999)
Vehicles per Hour
0
50
100
150
200
250
300
350
400
450
0:00-0:59
1:00-1:59
2:00-2:59
3:00-3:59
4:00-4:59
5:00-5:59
6:00-6:59
7:00-7:59
8:00-8:59
9:00-9:59
10:00-10:59
11:00-11:59
12:00-12:59
13:00-13:59
14:00-14:59
15:00-15:59
16:00-16:59
17:00-17:59
18:00-18:59
19:00-19:59
20:00-20:59
21:00-21:59
22:00-22:59
23:00-23:59
Time of Day
Avg. Weekday Volume by Hour
Avg. Weekend Day Volume by Hour
Avg. Day of the Month Volume by Hour

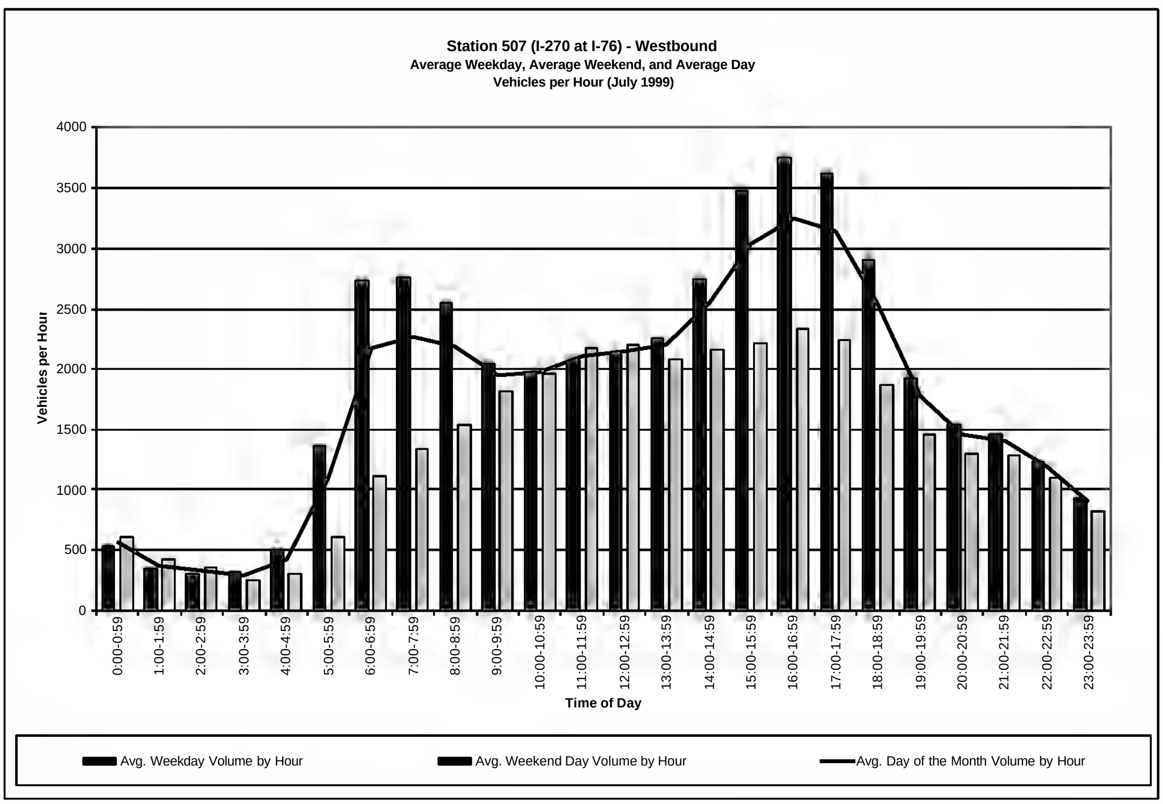

Station 504 (US 36 south of US 287)
Ratio of Weekday and Weekend Average Hourly Volume, by Direction
(Data for the month of July 1999)
Avg. Weekday Hourly Volume / Avg. Weekend Day Hourly Volum
Values greater than 1 indicate that the weekday average hourly volume for that period is greater than the weekend average hourly volume for that same period.
Time of Day
EB Weekday/Weekend Traffic Ratio
WB Weekday/Weekend Traffic Ratio

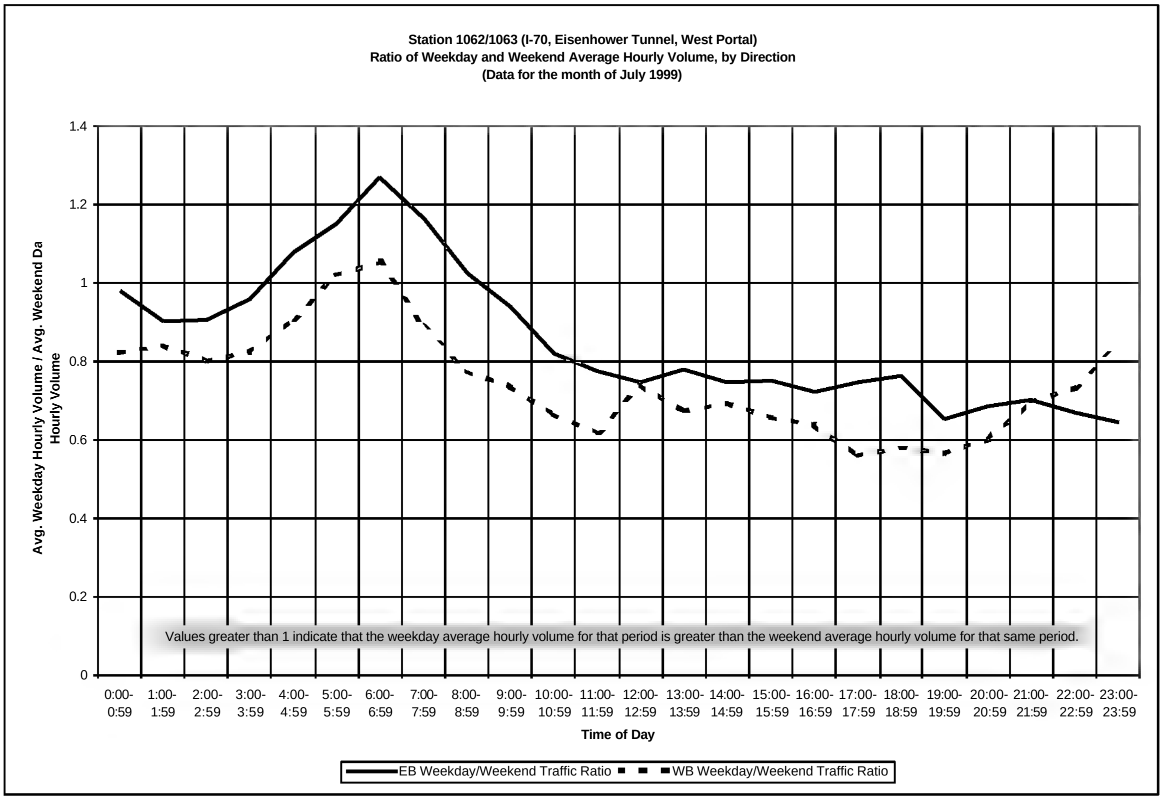

Station 504 (US 36 south of US 287) - Eastbound
Average Weekday, Average Weekend, and Average Day
Vehicles per Hour (July 1999)
Vehicles per Hour
Time of Day
Avg. Weekday Volume by Hour
Avg. Weekend Day Volume by Hour
Avg. Day of the Month Volume by Hour

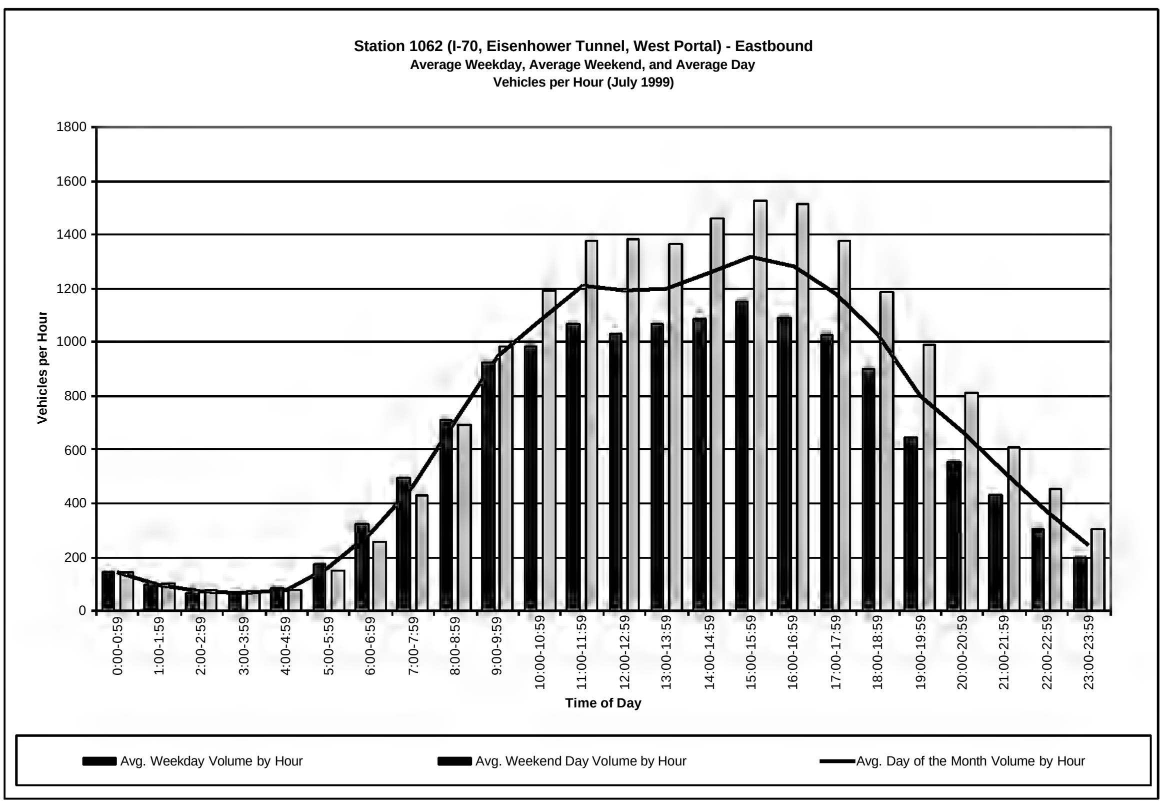

Station 504 (US 36 south of US 287) - Westbound
Average Weekday, Average Weekend, and Average Day
Vehicles per Hour (July 1999)
Vehicles per Hour
Time of Day
Avg. Weekday Volume by Hour
Avg. Weekend Day Volume by Hour
Avg. Day of the Month Volume by Hour

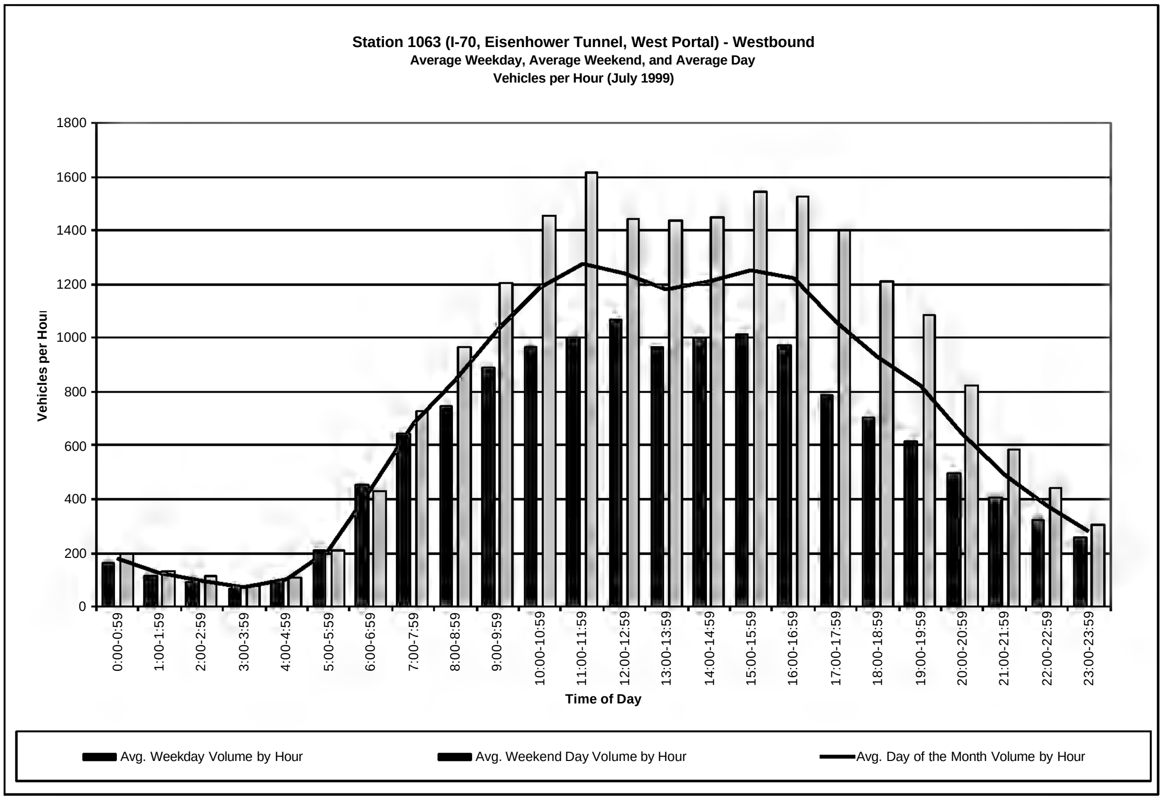

Station 507 (I-270 at I-76)
Ratio of Weekday and Weekend Average Hourly Volume, by Direction
(Data for the month of July 1999)
Avg. Weekday Hourly Volume / Avg. Weekend Day Hourly Volum
Values greater than 1 indicate that the weekday average hourly volume for that period is greater than the weekend average hourly volume for that same period.
Time of Day
EB Weekday/Weekend Traffic Ratio
WB Weekday/Weekend Traffic Ratio


Station 507 (I-270 at I-76) - Eastbound
Average Weekday, Average Weekend, and Average Day
Vehicles per Hour (July 1999)
Vehicles per Hour
0
500
1000
1500
2000
2500
3000
3500
4000
0:00-0:59
1:00-1:59
2:00-2:59
3:00-3:59
4:00-4:59
5:00-5:59
6:00-6:59
7:00-7:59
8:00-8:59
9:00-9:59
10:00-10:59
11:00-11:59
12:00-12:59
13:00-13:59
14:00-14:59
15:00-15:59
16:00-16:59
17:00-17:59
18:00-18:59
19:00-19:59
20:00-20:59
21:00-21:59
22:00-22:59
23:00-23:59
Time of Day
Avg. Weekday Volume by Hour
Avg. Weekend Day Volume by Hour
Avg. Day of the Month Volume by Hour


Station 507 (I-270 at I-76) - Westbound
Average Weekday, Average Weekend, and Average Day
Vehicles per Hour (July 1999)
Vehicles per Hour
0
500
1000
1500
2000
2500
3000
3500
4000
0:00-0:59
1:00-1:59
2:00-2:59
3:00-3:59
4:00-4:59
5:00-5:59
6:00-6:59
7:00-7:59
8:00-8:59
9:00-9:59
10:00-10:59
11:00-11:59
12:00-12:59
13:00-13:59
14:00-14:59
15:00-15:59
16:00-16:59
17:00-17:59
18:00-18:59
19:00-19:59
20:00-20:59
21:00-21:59
22:00-22:59
23:00-23:59
Time of Day
Avg. Weekday Volume by Hour
Avg. Weekend Day Volume by Hour
Avg. Day of the Month Volume by Hour


Station 1062/1063 (I-70, Eisenhower Tunnel, West Portal)
Ratio of Weekday and Weekend Average Hourly Volume, by Direction
(Data for the month of July 1999)
Avg. Weekday Hourly Volume / Avg. Weekend Da Hourly Volume
Values greater than 1 indicate that the weekday average hourly volume for that period is greater than the weekend average hourly volume for that same period.
Time of Day
EB Weekday/Weekend Traffic Ratio
WB Weekday/Weekend Traffic Ratio


Station 1062 (I-70, Eisenhower Tunnel, West Portal) - Eastbound
Average Weekday, Average Weekend, and Average Day
Vehicles per Hour (July 1999)
Vehicles per Hour
Time of Day
Avg. Weekday Volume by Hour
Avg. Weekend Day Volume by Hour
Avg. Day of the Month Volume by Hour


Station 1063 (I-70, Eisenhower Tunnel, West Portal) - Westbound
Average Weekday, Average Weekend, and Average Day
Vehicles per Hour (July 1999)
Vehicles per Hour
0
200
400
600
800
1000
1200
1400
1600
1800
0:00-0:59
1:00-1:59
2:00-2:59
3:00-3:59
4:00-4:59
5:00-5:59
6:00-6:59
7:00-7:59
8:00-8:59
9:00-9:59
10:00-10:59
11:00-11:59
12:00-12:59
13:00-13:59
14:00-14:59
15:00-15:59
16:00-16:59
17:00-17:59
18:00-18:59
19:00-19:59
20:00-20:59
21:00-21:59
22:00-22:59
23:00-23:59
Time of Day
Avg. Weekday Volume by Hour
Avg. Weekend Day Volume by Hour
Avg. Day of the Month Volume by Hour