

Development of Truck Models

Prepared for

Baltimore Metropolitan Council
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Executive Summary

This report documents the development of a new set of regional truck trip forecasting models for the Baltimore Metropolitan Council (BMC). BMC, along with many other agencies, has been using truck trip estimates that are based on data that is more than 30 years old. Given a renewed interest in air quality, and goods movement as part of intermodal planning, the agency has decided to update its truck models.

The difficulty in truck modelling is that good data on observed trip patterns is very rare. A truck survey recently conducted jointly with the Metropolitan Washington Council of Governments did not produce the kind of information that is usable for model development.

However, there were some fairly reliable Maryland DOT counts of truck volumes on numerous links in the Baltimore region. BMC engaged the services of a consultant who has pioneered the practical application of a methodology to synthesize a trip table from count data. Working "backwards" from the count data, the consultant not only created such a trip table, but then used it to develop a truck trip forecasting model that would produce link-level truck volumes with much improved accuracy. This effort was aided by extensive nationwide truck trip research recently published by the Transportation Research Board and USDOT's Travel Model Improvement Program.

BMC staff assembled year 2000 medium and heavy truck counts on a few hundred links across the modelled region. The consultant researched the literature to develop a new, interim set of generation/distribution/assignment models for both truck types. The consultant then applied a procedure called "adaptable assignment" to systematically adjust the interim model so as to better match the counts. This process resulted in a number of changes to the interim model and also produced a set of "calibration adjustment" factors. These adjustment factors are then multiplied by the output of the model, producing a new table whose assignment comes much closer to matching the count data. In addition, the consultant developed an improved method of modelling external and through truck travel. Separate models were developed for medium and heavy truck trips. The consultant also created a new model to estimate commercial light-duty vehicle trips, as documented in a separate report.

The result is a process that both exhibits reasonable sensitivities to the key input variables (employment by type and households) and has been shown to match 2000 counts to a fairly high degree of accuracy. A 2025 forecast was made with this new process and the results found to be reasonable. The consultant has also provided the staff with a set of TP+ setups with which to apply the new models.

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1 Introduction

This report documents the development of a new set of regional truck trip forecasting models for the Baltimore Metropolitan Council (BMC). In recent years, BMC has been updating various parts of its regional travel forecasting model. The truck model was developed in the mid-1960's, using data from 1962 and has not been revised since. BMC staff have accumulated some evidence that this model was severely underestimating actual truck traffic. As part of its on-going model improvement program, BMC decided in 2001 to start the process of revising the truck model. In this report, the "old" truck model is referred to as the "MC96 model", since that is the label given to the most recent BMC model validation, completed in September 2001.

As used in this report, the term "truck model" actually refers to two separate models: one for heavy trucks and one for medium trucks. Segmentation of these two categories is based on the Federal Highway Administration's (FHWA) "F-13" classification scheme. "Heavy" trucks are defined as vehicles with three or more axles (F6 - F13 in the FHWA scheme). "Medium" trucks are vehicles with two axles and six tires (FHWA's F5). In the MC96 model, medium trucks were referred to as "light trucks". The terminology has now been changed to avoid confusion with the more commonly used definition of "light trucks": pickups, vans, minivans, and sport-utility vehicles (SUVs).

Truck modelling has taken on more importance in recent years, for a couple of reasons. Perhaps the primary reason is that trucks make a disproportionately high contribution to the region's mobile source emission inventory, especially for NO_x and particulates. The need to meet increasingly stringent regional emission budgets has caused most planning agencies to examine every possible emission source in greater detail. Another reason is an increasing emphasis on goods movement and the role of the region's transportation system in facilitating goods movement, and by implication, the economy. Baltimore's role as a shipping hub makes this even more critical than in other cities.

BMC staff found that there was very little available information on which to base revisions to the truck model. Thus, a truck trip survey was conducted in 1996. This was a major effort, conducted jointly with the Metropolitan Washington Council of Governments (MWCOG) that included over 400 locations throughout the Baltimore/Washington region. More than 1,800 trips were covered by the survey. After the survey was completed, detailed examination of the data indicated that the variability in truck trip rates was so high, that the data collected could not be used

with reasonable confidence to develop new models. Problems with geocoding and identifying different types of trucks were also noted. The analysis disclosed that many of the factors that actually influence trip rates were beyond the scope of the survey. This has proved to be a common finding of truck surveys recently performed across the U.S. These findings caused BMC staff to reject the idea of updating the model with this data (Reference 1).

An older truck study conducted by Baltimore City Planning staff was consulted (6), but that report focused on trip rates per 1,000 square feet, for specific building types. This information may be useful in the context of site traffic analyses, but is not suitable for regional model analysis.

Other cities faced with the need to update a model with little survey data have turned to an innovative approach that approaches this problem in a more indirect fashion. This new approach relies almost entirely on counts conducted throughout the region. The availability and relative accuracy of classification counts makes them a reliable and usable source of data for truck modelling. The new approach involves using these counts as a basis for synthesizing a truck trip table. That table is then used to "inform" the model, providing a more credible basis for adjusting the model's parameters. In addition, the method provides a systematic calibration adjustment that helps the model to achieve fairly high accuracy of assigned truck volumes on a link-by-link basis.

This report documents the use of this new approach, called "adaptable assignment", to develop a new truck model for BMC.

This report is organized into eight chapters, including this Introduction:

- 2 Truck Modelling Issues
- 3 MC96 Truck Model
- 4 Interim Model
- 5 First Adaptable Runs
- 6 Final Adaptable Run
- 7 Forecasting
- 8 Final Model

In addition, the reader is referred to a separate report describing the development of a new BMC model for "Commercial" trips. These include passenger cars, light trucks, SUV's, vans, and other vehicles not defined under Medium or Heavy Trucks, which are used for commercial purposes (i.e., not passenger transportation *per se*). The Commercial model was developed at the same time as the new truck model and covers a type of trip that heretofore was not separately recognized in the BMC model.

2 Truck Modelling Issues

State of the Art

As part of this project, the consultant made a brief review of the state of the art in truck trip modelling. Two recent reports greatly facilitated this effort: *Quick Response Freight Manual* (2) and NCHRP Synthesis 298, *Truck Trip Generation Data* (3). These reports provide an excellent overview of current practice and key issues concerning truck trip modelling.

The first issue is: what is the context of the model? There are three levels of analysis detail: 1) national or statewide analyses of tax payments, pavement condition, or general rail vs. truck movement; 2) regional analyses concerned with link volumes, emissions, and corridor studies; and 3) local studies in which traffic engineers are looking at noise, geometrics, pavement, or loading facilities. These are very different kinds of analyses, calling for different kinds of models. Most of the focus of the literature is on regional truck models, and that is the level that this report is concerned with.

One of the most important issues is the definition of just what is a "truck". Models based on registration data use gross vehicle weight (GVW) definitions. Models based on classification counts use the number of axles as their criterion. These two definitions are not consistent with each other and create difficulties in comparing models and results. The selection of an appropriate definition also hinges on the purpose of the truck analysis: is it mainly for motor carrier/tax policy, pavement analysis, or emissions calculation?

Another key issue is the structure of the model. So-called "commodity-based" models attempt to analyze the flow of all goods from their source, through various transformations, and then on to the final consumer. This kind of analysis permits the explicit consideration of trade-offs among different freight modes (e.g., highway, air, rail, water). Many planners consider this the "ultimate" in freight modelling, but it is generally considered a goal that might be attained in the future, not something that is truly practical today. The alternative is a "vehicle-based" model, which simply estimates truck trips. This is the form taken by almost all operational truck trip models. The literature considers this to be a reasonable interim approach until such time as commodity-based models become more widely used and accepted.

The difficulty in conducting truck trip surveys is well known. One problem is that almost all regional travel models consider the basic unit of travel to be the "trip": a movement between an origin and a destination. For many trucks, however, the unit of travel is instead a "tour": a series of

connected trips throughout the day. This not only complicates the survey itself, but it makes it extremely difficult to translate tour movements into the origin/destination trip approach taken by most models. An even more significant problem is simply one of participation. Trucking firms treat travel data as proprietary information and are not willing to have this information made available to the public (or their competitors). These firms are not accustomed to working with public planning agencies and often distrust or misunderstand the purpose of the surveys. Even when the trucking company is cooperative, truck drivers themselves usually view surveys as nothing more than an unwarranted and unnecessary intrusion on their workday. Thus, it should come as no surprise that reliable, usable data is rarely achieved in trucking surveys. A possible exception is that roadside intercept surveys, if conducted in a safe and efficient manner, can be very useful in obtaining data on truck trip movements that are external or completely through the region.

Those analysts lucky enough to obtain usable data on truck trips are being confronted with another obstacle: the measures of land use that are causally related to truck activity are generally not among the data items that are available at the traffic zone level, or are forecasted. As a result, in almost all cases, planners try to relate truck travel to the variables that *are* available. The outcome is usually a relatively crude model that relates truck trips to employment and population. The results are usually less than satisfactory, but are justified by noting that "trucks are only 5% of all trips". While this may be true in total, trucks do account for a higher share of traffic on the major roadways and heavy trucks also utilize a greater share of roadway capacity than their volumes indicate.

In summary, the state of the art in truck trip models is relatively dismal, but starting to improve. Substantial enhancements in these models will need to await the widespread acceptance and use of automated, non-intrusive data collection technology (perhaps GPS-based) and the development of traffic-zone-level data that is more closely related to goods movement. At least in recent years, more planning agencies are paying greater attention to these needs.

Factors Affecting Truck Forecasting

The above issues relate mainly to the development of a model which can adequately describe *today's* truck travel. Forecasting truck trips proves to be even more difficult than forecasting personal travel, for a number of reasons. Creating a model that accounts for all the factors that are likely to affect future truck travel would require a crystal ball. One needs only to look at the last 10 years to understand some of these factors.

One of the most important phenomena to affect truck travel over the past two decades is the change in goods movement technology. Containerization has affected practically all aspects of goods movement, including ship, rail, and truck. Containerized freight movement now represents the majority of goods moved at all U.S. ports, for example. In a related development, trailer on flat car (TOFC) and container on flat car (COFC) have created tremendous opportunities for intermodal coordination and efficiency that did not exist only a few years ago.

Another similar development (also related to the above) is the sharp rise in freight labor productivity. Over the past 20 years, the number of truck trips per employee has risen sharply. The nature of American industry has changed in recent years and improvements necessitated by international competition have practically revolutionized the freight industry. One example of this is *just-in-time* (JIT) delivery, in which industries reduce their warehousing space because they no longer stockpile materials used in production. These materials are delivered by suppliers on the day (sometimes at the hour) they are needed and they move directly from the loading dock onto the production line. JIT requires a veritable ballet of truck movements, organized and scheduled with great precision and timing. Obviously, it also increases the number of truck trips serving a manufacturing plant. This kind of operation barely existed ten years ago and now it is commonly used throughout the manufacturing sector, particularly for motor vehicle assembly.

As if recent changes in technology and productivity weren't drastic enough, the past decade has also seen major political changes that affect goods movement. The increase in the global nature of the U.S. economy, aided by actions such as the North American Free Trade Agreement (NAFTA), has had a profound effect on all forms of freight movement. One of the earliest impacts of NAFTA was a sharp increase in truck traffic across the borders with Canada and Mexico, as U.S. companies sought to improve their operations by using facilities in those countries.

Many other external factors have been seen to strongly influence truck travel in recent years, including: deregulation, changes in weight and size limits, fuel prices, and centralized warehousing.

The above commentary serves to highlight how difficult truck forecasting can be, especially in light of the limited resources typically devoted to it. Forecasting freight is certainly no less challenging (and probably more so) than forecasting personal travel. While there will doubtless continue to be changes in technology and productivity in the future, it is not feasible to incorporate them into the model or to estimate their impact at this time. This suggests a need to continually revisit and update the truck model at regular intervals.

3 MC96 Truck Model

Generation

The BMC MC96 truck model is the only remaining component of the original Baltimore Region travel demand model developed in 1973 (1). The generation model for I/I trips is shown in Table 1.

Table 1
MC96 Truck Generation Model

$$\begin{aligned} &\text{If Percent Developed in Zone } \geq 40 \\ &\quad T_{LT} = 0.17588 * \text{Pop} + 0.07504 * E_{NR} \\ &\quad T_{HT} = 0.02065 * LF + 0.01077 * E_{NR} \\ &\text{If Percent Developed in Zone } < 40 \\ &\quad T_{LT} = 0.10086 * \text{Pop} + 1.55434 * E_R \\ &\quad T_{HT} = 0.33395 * E_R \end{aligned}$$

Percent Developed is the estimated percentage of the zone that contains residential, office, retail, or industrial development

T_{LT} is light truck (now "medium") productions (= attractions)

T_{HT} is heavy truck productions (= attractions)

Pop is population

LF is resident labor force

E_{NR} is non-retail employment

E_R is retail employment

This model is typical of most truck generation models. However, it is a bit curious that in the high "percent developed" equations, the coefficients on Population and Labor Force are more than twice those on Employment. It would seem more intuitive that one employee should generate more truck trips than one resident. The literature search found no other model in which the coefficient on Population exceeded the coefficient on Employment.

This model is based mostly on zonal variables that BMC currently estimates. However, the origin of the "percent developed" variable is undocumented and this variable is not used for any other purpose in the model chain. Also, the staff apparently do not keep this variable updated. In the MC96 model validation for 1996, this model produced the internal/internal trip totals shown in Table 2.

Table 2
MC96 Truck Trip Generation Results (I/I)

Light (Medium) Trucks		To	
From	Baltimore	Washington	Total
Baltimore	468,300	41,600	509,900
Washington	39,100	524,000	563,100
Total	507,400	565,600	1,073,000

Heavy Trucks		To	
From	Baltimore	Washington	Total
Baltimore	34,100	4,000	38,100
Washington	3,900	57,200	61,100
Total	38,000	61,200	99,200

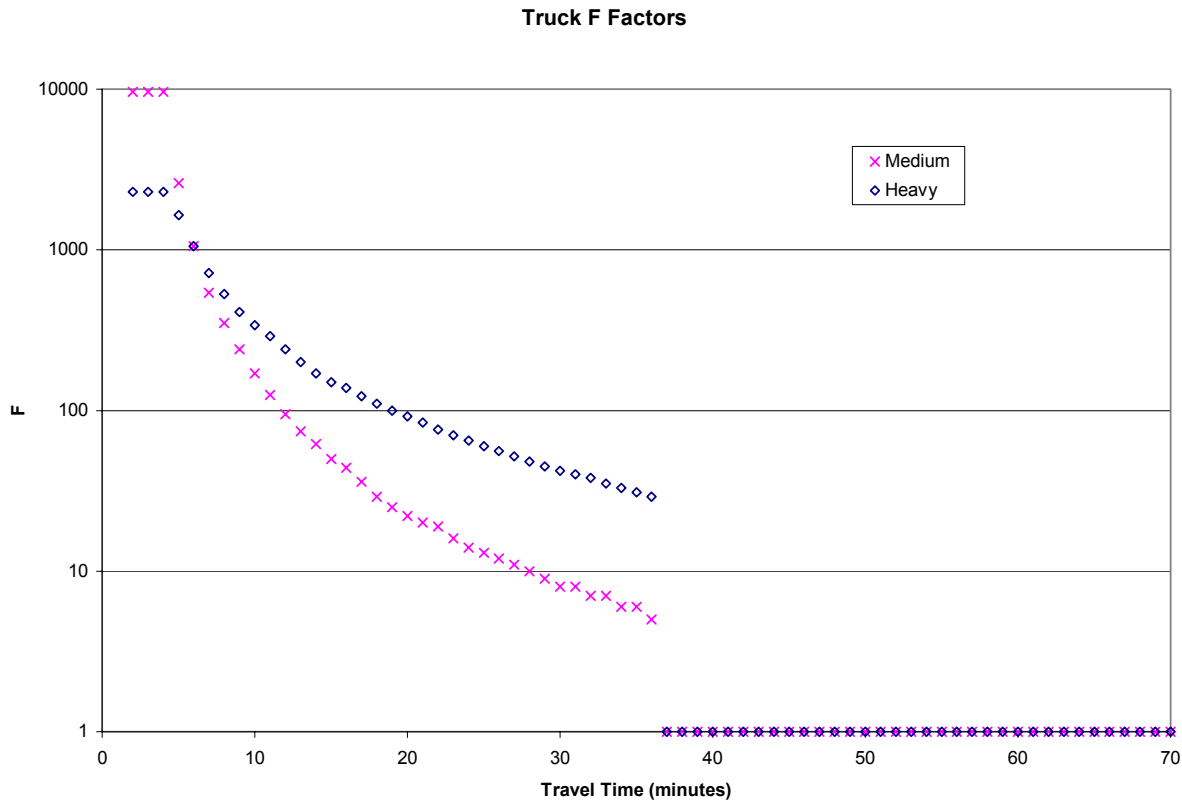
The MC96 model did not estimate external truck trip ends, *per se*. These are input directly to the main BMC trip generation step. No documentation could be found describing the calculation of these trip ends. In 1996, approximately 35,000 light (medium) truck external productions and 35,000 external attractions were input, along with about 22,000 heavy truck external productions and 21,000 external attractions. In the trip end normalization process, the Productions are held constant and the external Attractions are held constant. The internal Attractions are then adjusted to ensure that the total Productions (internal + external) match the total Attractions. As a result, the final internal Productions might not match the final internal Attractions by zone. This method ensures that the input external trip ends are not modified.

It is not uncommon for external trip ends to be calculated in an off-model process and added to the input data stream, as BMC has been doing. However, it is difficult to evaluate the MC96 process to estimate external truck trip ends, since this process is not documented. Many recently developed models have found that a more systematic calculation of external trip ends both simplifies the setup of the model and provides an "audit trail" that can be checked.

Distribution

The MC96 truck distribution model uses a standard gravity model formulation to allocate Productions to Attractions. The F factors are shown in Figure 1. It is presumed that these factors were derived in the 1973 calibration. The shape of these curves is fairly typical, although the sharp drop-off to an F of 1 at 36 minutes is rather curious. These curves produced average trip lengths of 17.5 minutes for light (medium) trucks and 34.0 minutes for heavy trucks in 1996 (all trips). In the absence of any other information, it is not feasible to evaluate the accuracy of these estimates.

Figure 1
MC96 Truck F Factors



One curious feature of the MC96 truck trip distribution is that no distinction is made between internal zones and external stations. The BMC model application procedure uses the same gravity formulation to allocate trips among all internal zones and external stations. This is not consistent with the "best practice" in other areas, which treats internal and external trips separately for distribution purposes. Further, the MC96 process allowed external station trips to be allocated to other external stations. This is also not generally considered an appropriate way to calculate through (X/X) trips. Worse, the MC96 method did not prevent the estimation of intrazonal trips at external stations. While this is a relatively small error in the overall model chain, it is clearly illogical.

Time of Day

The MC96 truck time of day model is a fairly straightforward set of fixed factors that allocate the daily trips by five time periods, as shown in Table 3. This is pretty much the "best practice" in temporal modelling, which is still an emerging area of practice around the country. The source

of these fractions is undocumented, however. The same set of fractions is used for light (medium) and heavy trucks.

Table 3
MC96 Truck Time of Day Factors

Period	Fraction
Night (12 M - 6 AM)	9.67%
AM Peak (6 - 10)	35.01
Midday (10 AM - 3 PM)	15.09
PM Peak (3 - 7)	31.24
Evening (7 PM - 12 M)	8.99

Assignment

In the MC96 assignment procedure, both light and heavy trucks are added to the total vehicle trip table for each time period, prior to assignment. No special provision is made for trucks, either to restrict them from certain roadways, or to reflect their impact on capacity. This is a fairly common practice, although most urban areas with parkway facilities are starting to use the multi-class assignment feature of most transportation planning software packages. This feature permits the separate assignment of truck trips to a network that includes certain roadways from which trucks are prohibited.

BMC staff's analysis of the MC96 assignment indicates that the 1996 assigned daily heavy and medium truck volumes are very inaccurate. Staff analysis was concentrated around the Port of Baltimore and major freeways, e.g., I-95, I-695, etc. The results showed that heavy truck traffic was underestimated by about 70% while medium truck traffic was underestimated by about 30%. Apparently, data from the 1973 model calibration showed a similar underestimation (1).

It is not possible for the consultant to evaluate directly the accuracy of the MC96 truck model, since 1996 truck counts were not made available. However, the consultant did assign BMC's year 2000 truck trips ("MC00") which are based on the MC96 model structure. This was done in such a way to permit the comparison of medium and heavy truck assigned volumes with available year 2000 counts. This comparison partially confirmed the staff's assessment: for light (medium) trucks, the total error (sum of the assigned volume on counted links/sum of the counts) was +265% and the percent root mean square error (%RMSE) was 482%. For heavy trucks, the total error was -64% and the %RMSE was 131%. (The % RMSE is a good overall indicator of assignment error, accounting for both over- and under-estimation. Lower values are better.) Further analysis by BMC staff revealed that the MC96 medium truck model vastly overestimated traffic in residential areas while

underestimating it around industrial and CBD areas. This is apparently due to the MC96 medium truck model having higher coefficients for population than for employment as noted on page 6. As a result, it is apparent that the MC96 truck model does not estimate accurate truck volumes at the link level.

Other Models

The consultant examined truck trip models from other urban areas. These include Washington, DC, Atlanta, New Orleans, Raleigh, and Lehigh Valley, PA. Although these models do not have a great deal in common, a few generally typical practices can be identified:

- Trucks are often segmented into two groups: heavy and medium. "Medium" sometimes includes light-duty commercial vehicles, but an emerging practice is to use a separate model for commercial light trucks, vans, and automobiles.
- External trip ends have often been defined using an "off-model" procedure. An emerging practice is to estimate an external share based on the zone's distance to the cordon.
- Truck models are usually based on old survey data (e.g., 1960's).
- Truck generation models are regression equations using population (or households) and employment by different types, with no constant term. The coefficient on population is smaller than that on employment.
- Zonal productions and attractions are set equal to each other.
- Special time of day or assignment procedures for trucks are rarely used.

4 Interim Model

Approach

This study takes an innovative approach to the problem of estimating truck trips. The premise of this approach is that it is not generally feasible to obtain statistically valid survey data on truck movements, due to the diversity of truck travel, the difficulty of conducting the surveys, and the low survey response rates. Thus, the traditional method of calibrating truck trip rates is not workable. However, it should be possible to obtain relatively accurate counts of truck volumes by type on a number of roadway segments throughout the region. A number of researchers have addressed the problem of using count data to "work backwards" to obtain a zone-to-zone matrix of trips. The consultant has developed a way to do this, called "adaptable assignment", that is quick, simple, and easily understood (4). If the MC96 model can be revised (or replaced with a model from the literature) such that the total estimated truck trips more closely match the truck counts, then the adaptable assignment process can be applied. This will produce a new truck trip table, whose differences from the initial table can be analyzed to identify where changes to the initial model are needed. This can be done separately for medium and heavy trucks.

A variation of this approach was recently used to develop an estimate of truck trip volumes for the new travel model for the New York metropolitan area (5).

Interim Model

An important element of this approach is to start with an estimated trip table that is "in the ballpark". The consultant's experience has shown that the better the starting trip table, the better the final results. Analysis by BMC staff and the consultant has indicated that the MC96 truck model produces volumes that are not too close to the counts. Thus, the MC96 model is likely to be unsuitable as a starting point. The consultant recommends starting with a new model, derived from the literature and adjusted to produce base year truck trip totals that are significantly different from the MC96 model. In addition, the consultant recommends a completely different method of estimating external and through truck travel. This new model is referred to as an "interim model", since it is subject to change during this project.

The literature review indicated that there are so many differences among existing truck models (definition of "truck", independent variables used) that creating an amalgam of several areas' models is not practical.

The consultant recommends that the interim model should be adapted from the Phoenix truck model, as documented in the *Quick Response Freight Manual* (2). This model is considered a reasonable "default model" by the authors of that manual, because it provides an internally consistent set of rates that have been adjusted to account for survey under-reporting and external travel. A revised external truck model procedure has also been developed. In addition, the trip distribution and assignment steps have been modified. These changes are described below.

Truck Zones

The interim model also accounts for zones in which there is strong reason to believe that the truck trip activity is higher than the standard trip rates would indicate. The consultant believes that the most important zones are few enough in number that they can be identified individually and classified in a way that allows the interim model to account for them. Although no data are available to specifically determine the increase in truck trips for such areas, a reasonable estimate can be made and confirmed or revised in the adaptable assignment process.

Six types of facilities have been identified. In most cases, there is only one such facility in each zone. When there are more than one, the zone is classified according to the most important facility. In addition to the six types, this classification scheme divides the facilities according to their relative scale: smaller vs. larger. BMC staff have determined that the level of 300 truck trips per day should generally be used to distinguish smaller from larger facilities. This results in 12 possible categories. Each "truck zone" is classified into one of these categories.

Although these classifications are general, the consultant believes that this is a reasonable trade-off against the need to maintain and forecast this data item. Table 4 lists the classifications and the zones that BMC staff have classified for 2000. BMC staff identified zones with high truck activity by working with the BMC Freight Movement Task Force and Technical Committees and by meeting with representatives from the Port of Baltimore and Metropolitan Washington Council of Governments. Figure 2 shows the 113 zones classified by BMC staff as truck zones from their 1,326 zone structure. The six truck zone types are defined below:

- Business District: core area of central business districts, major retail areas (shopping malls), college campuses
- Warehouse/Manufacturing: warehousing, manufacturing, and processing facilities, industrial parks
- Intermodal Transfer: facilities where freight transfers between trucks and another mode - mainly the port areas

- Airport: BWI (a special category)
- Institutional/Other: landfills, quarries
- Delivery/Medium Truck: facilities that process mail or express delivery packages

Table 4
Truck Zones

Type	Scale	
	Larger	Smaller
Business District	116,121,124,125,139,140,161,1015-1020,1026,1027,1038	63,258,342,346,347,368,429,461,462,473,484,529,530,536,541,610,611,630,653,755,759,762,793,828,829,955,973,975,1053,1054,1056,1059,1081,1097,1138,1202,1203,1273,1274
Warehouse/Mfgr.	167,413,725,881,1009,1145,1197,1249,1265	180,184,658,734,746,750,767,869,872,994,995,1013,1144,1192,1205,1258
Intermodal Transfer	168,177,178,195,207,709,1010	94
Airport	224	N/A
Institutional/Other	206,265,464,841	190,314,319,463,570,768,769,770,900,910,915,1096,1269,1270
Delivery/Medium Truck	(none identified)	1034,1098,1146,1148

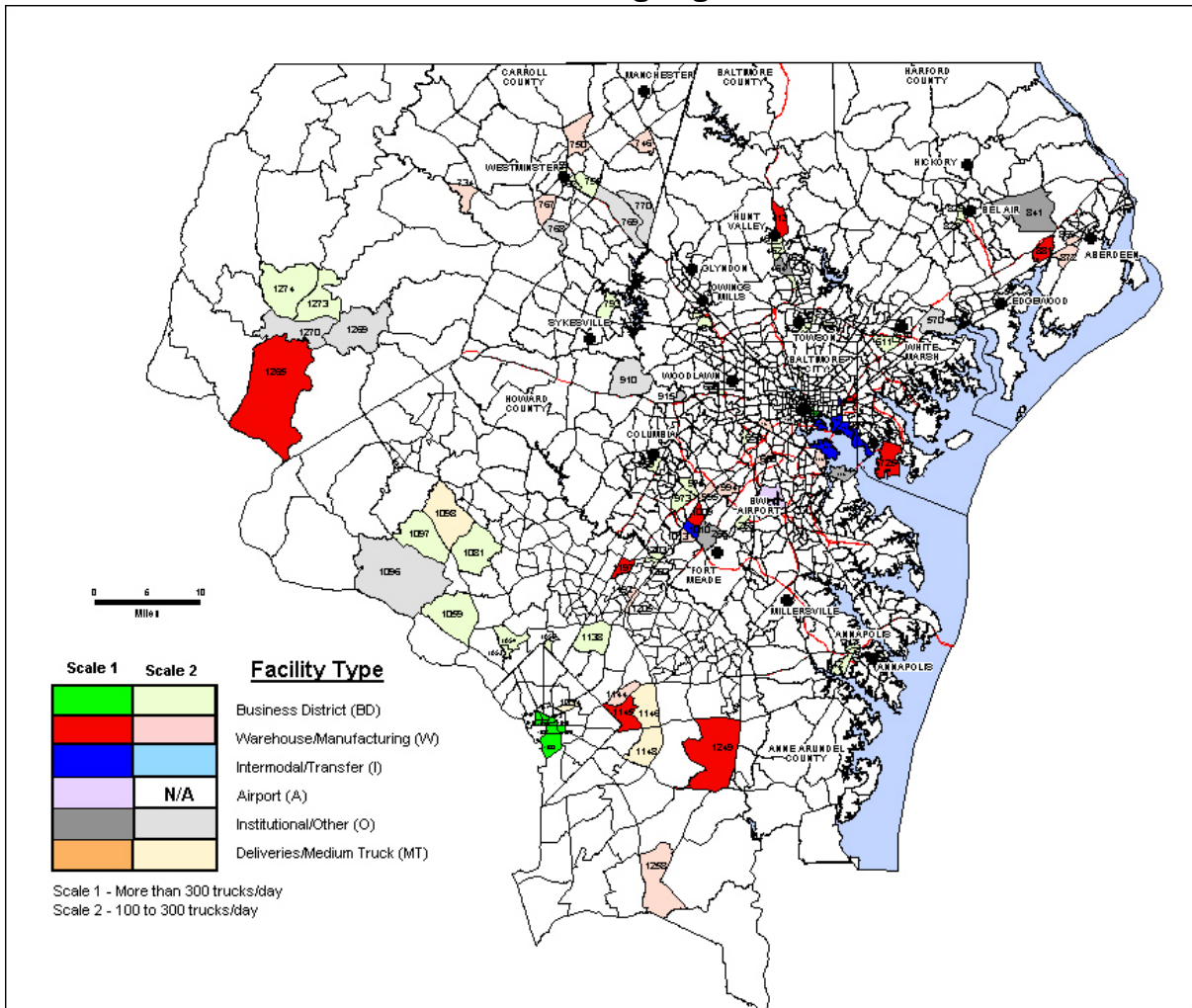
Generation

The recommended interim truck trip generation model is shown in Table 5. This is based on the adjusted Phoenix model, as documented in the *Quick Response* manual (2). The coefficients have been adjusted to match the BMC truck category definitions and to use the new BMC categories of employment by zone (a sample of this data is shown in Appendix A). This interim model has been applied to BMC's year 2000 zonal socioeconomic data and the coefficients adjusted in order to calculate the preliminary target number of trips by type, as estimated by BMC staff. The consultant has developed initial factors that increase the estimated truck trips for the truck zones, by type.

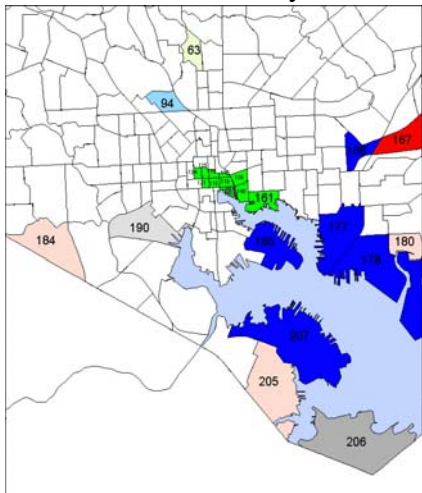
As applied to BMC's new 2000 zonal data, this model estimates 345,000 daily medium truck trips and 476,000 daily heavy truck trips. Of the medium truck trips, 310,000 are I/I and 35,000 are external. Of the heavy truck trips, 407,000 are I/I and 69,000 are external. In order to achieve the initial targets, the Phoenix rates were reduced by 25% for medium trucks and increased by 5% for heavy trucks. The consultant believes that this is a relatively modest adjustment that serves to validate the approach and the trip rates chosen. These trip rates, the "macro" adjustments, and the truck zone factors constitute the interim model, that serves as the starting point for the adaptable assignment process. All of the coefficients and factors in Table 5 are subject to being modified as a result of subsequent analyses.

Figure 2
 Truck Zone Map

BMC Modeling Region



Baltimore City



Baltimore CBD

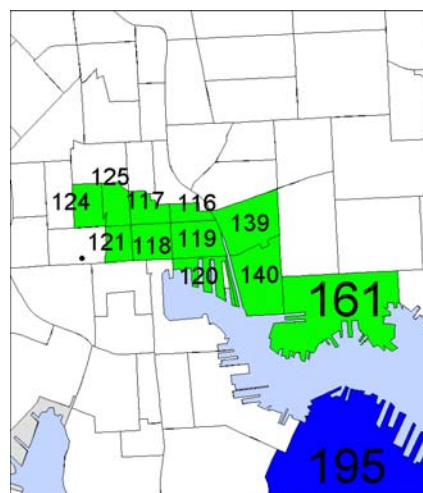


Table 5
Interim Generation Model

$$MT = 0.75 * (0.178 * INDEMP + 0.177 * RETEMP + 0.048 * OFFEMP + 0.069 * HH)$$

$$HT = 1.05 * (0.199 * INDEMP + 0.141 * RETEMP + 0.029 * OFFEMP + 0.068 * HH)$$

INDEMP is Industrial Employment
RETEMP is Retail Employment
OFFEMP is Office Employment
HH is Households

Factor for truck zone type:

Type	Scale			
	Larger		Smaller	
	MT	HT	MT	HT
Business District	2.0	2.0	1.5	1.5
Warehouse/Mfgr.	1.2	3.0	1.1	2.0
Intermodal Transfer	1.2	3.0	1.1	2.0
Airport	3.0	3.0	N/A	N/A
Institutional/Other	1.2	3.0	1.1	2.0
Delivery/Medium Truck	4.0	2.0	2.0	1.5

External Model

The consultant proposes an entirely new procedure for estimating external truck trips. This method assumes that the generation model estimates total trip ends, both I/I and external (which includes I/X and X/I). The external share of the total trip ends is then modelled as a function of the zone's distance to the model's cordon, along the highway network. Zones that are closer to the edge of the modelled region will generally have a higher share of external trips than other zones.

In addition, the external trip ends at the internal zones that are calculated in this manner are balanced to match the total external trip ends at the external stations. In this way, the external truck trip volumes at the cordon are conserved and are assumed to be the "correct" volumes.

The proposed external share model is shown in Figure 3 and Table 6. This calculation is performed for each internal zone. This model was adapted from a similar model calibrated from survey data for Berks County, PA and has been adapted to other areas as well.

Figure 3

Interim External Truck Model

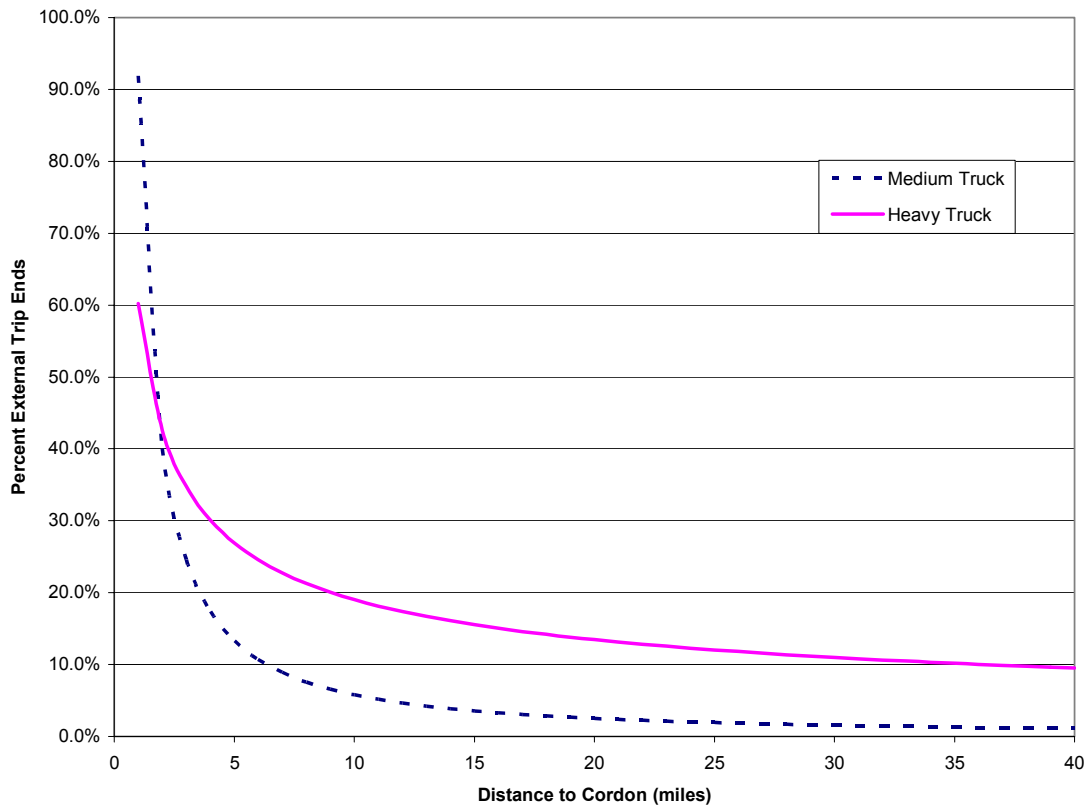


Table 6
Interim External Truck Model

$$\text{Percent External (MT)} = 0.919 * D^{-1.2}$$

$$\text{Percent External (HT)} = 0.602 * D^{-0.5}$$

Where:

D = distance to nearest external station (via highway net), miles

At the external stations, the consultant split the truck trips by type into external vs. through. This analysis was based on 2000 total weekday volumes posted on the network and a preliminary 2000 total through trip table provided by BMC. The consultant first calculated the percentage of total through-trips by station. It is estimated that medium trucks are less likely to make through-trips than the general stream of traffic, since medium trucks are typically short-haul delivery vehicles. In contrast, heavy trucks should be more likely to make through-trips, since they are frequently long-haul carriers.

In addition, the through trip percentage (through-trips/total trips at cordon) logically varies by facility type. Freeways have by far the largest

through trip percentage, because they are the major routes through the region. However, local roads typically have few, if any, through-trips. Based on the relationships and assumptions described above, the consultant developed a look-up table to estimate the external trip share (= 100% - through trip share) for each station, as shown in Table 7.

Table 7
Truck External Shares by Road Type

Road Type	MT External %	HT External %	Description
1	87%	81%	freeway
2	92%	85%	multilane divided
3	92%	85%	center turn lane
4	98%	95%	undivided
5	98%	95%	urb/sub arterial
6	100%	100%	rural hwy
7	100%	100%	substandard
8	100%	100%	local
9	100%	100%	ramp 1
10	100%	100%	ramp 2
11	100%	100%	ramp 3
12	100%	100%	ramp 4
13	100%	100%	ramp 5
14	100%	100%	cent connector

Applying this table to the truck trip volumes at the external stations produces the estimated 2000 truck external trip ends at the external stations, as shown in Table 9. The internal and external trip ends are configured as shown in Table 8.

Table 8
Configuration of Truck Trip End File

Zone	I/I Prod	I/I Attr	Ext Prod	Ext Attr
1	A	A	D	O
...	B	B	E	O
1284	C	C	F	O
1285	0	0	0	G
...	0	0	0	H
1326	0	0	0	I

Note: Letters represent non-zero values.

Table 9
2000 External Truck Trip Ends

TAZ	Road	MT Ext Vol	HT Ext Vol
1285	MD 2	560	362
1286	MD 4	1,146	3,866
1287	MD 381	208	88
1288	MD 5/US 301	1,892	8,012
1289	MD 210	800	354
1290	I-495/I-95	5,106	16,248
1291	I-395/US 1	4,000	-
1292	Arl. Mem Bridge	700	-
1293	I-66	1,400	-
1294	Key Bridge	640	-
1295	Chain Bridge	308	-
1296	I-495	7,852	9,952
1297	US 15	730	1,354
1298	MD 478/MD 79	116	118
1299	US 340	718	1,330
1300	US 40 Alt.	270	238
1301	I-70	1,308	8,190
1302	US 40	212	142
1303	MD 17/MD 77	94	40
1304	MD 550	62	24
1305	MD 140	372	502
1306	US 15/US 15 Bus	670	2,230
1307	Harney Rd	58	60
1308	MD 194	214	212
1309	MD 97	348	416
1310	Old Hanover Rd	176	96
1311	MD 30	536	1,786
1312	MD 86	202	152
1313	Middletown Rd	172	102
1314	MD 45	180	44
1315	I-83	348	3,976
1316	MD 23	88	80
1317	MD 24	38	12
1318	MD 624	90	104
1319	MD 165	348	202
1320	Old Pylesville Rd	38	162
1321	MD 646	14	4
1322	MD 623	36	6
1323	US 1	298	314
1324	I-95	2,454	12,558
1325	US 40	780	1,464
1326	US 50/US 301	3,060	7,166
Total		38,642	81,966

Distribution

As noted above, the MC96 truck models produced average trip lengths of 17.5 min for medium trucks and 34.0 min for heavy trucks (this includes I/I and externals, but not X/X). Although some reviewers have questioned the validity of these values, no specific evidence could be found to refute them. In fact, a tabulation of the 1996 Baltimore-Washington truck survey conducted jointly by MWCOG and BMC indicated an average trip length for I/I heavy truck trips of 17.5 min. This compares very closely to the MC96 average trip length for I/I heavy truck trips of 16.8 min and suggests that the MC96 trip lengths are reasonably accurate. Thus, they were used as target values for the calibration of a new set of F (friction) factors. The gamma function has become a popular way to define F factors in many areas, because it has the proper shape and is easy to calibrate. This function was adopted for use in this model. Its equation is as follows:

$$F = \alpha * t^{\beta} * e^{(\gamma t)}$$

where:

t = travel time, minutes

α , β , γ = calibrated coefficients

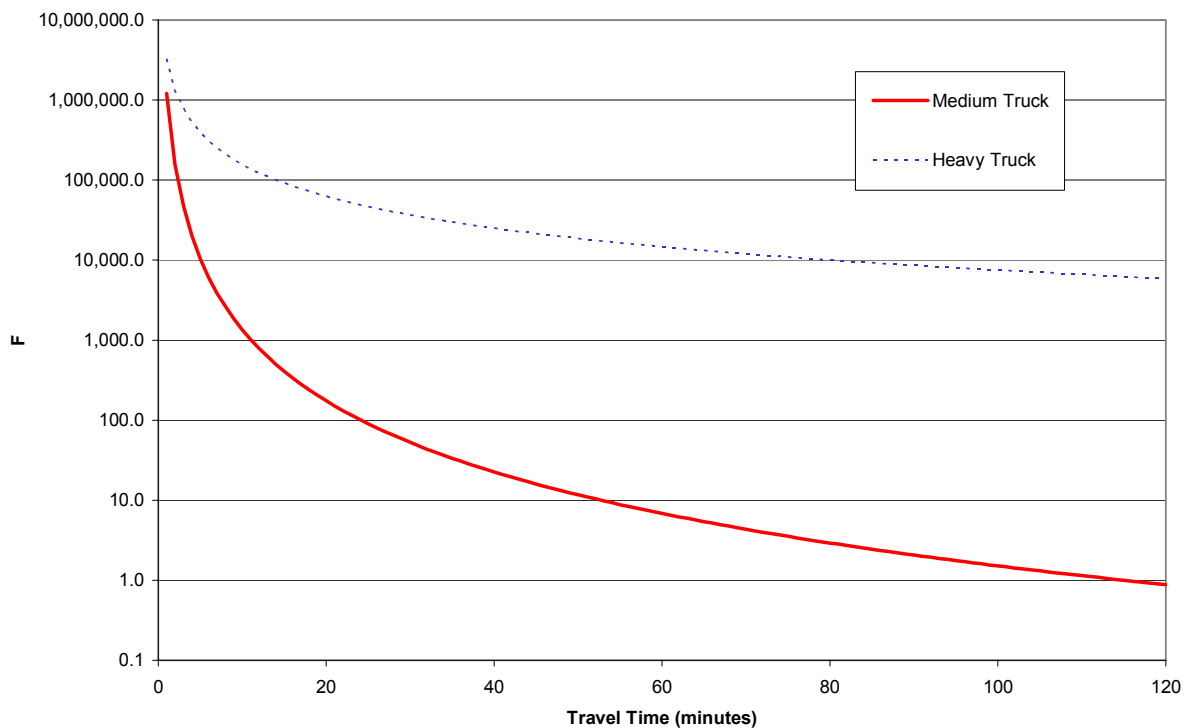
The consultant tested various coefficient values, using the newly estimated trip ends, until coefficients were found that produced a trip table that had the target average trip lengths, for 2000. The same F factors were applied to I/I and external trips and then the resulting tables were summed to determine the overall average trip length. F factors were computed for travel times from 1 to 120 minutes. Table 10 shows the final gamma function coefficients and Figure 4 shows the resulting F factor curves. (A gamma value of zero basically converts the equation to an exponential model.) The estimated trip lengths are 17.4 min for MT and 33.8 min for HT, both within 1% of the MC96-based target values.

Table 10
Interim Truck F Factor Coefficients

	α	β	γ
Medium Truck	exp(14.0000)	-2.95	0.0
Heavy Truck	exp(15.0000)	-1.32	0.0

For through (X/X) trips, the consultant started by examining the 2000 total X/X daily vehicle trip table provided by BMC. This was found to be inadequate for describing truck X/X movements. Instead, the

Figure 4
Interim Truck F Factors



consultant examined the external station locations where X/X truck trips should be expected. Then, by inspecting the external station geography and making assumptions about likely X/X patterns (as well as *unlikely* patterns), the consultant developed an "X/X pattern file". This was used to create a seed matrix, which was then Frated to match the estimated number of daily X/X truck trip ends at each station, by truck type. The resulting tables were assigned to the network and the loading patterns examined to confirm that they represent a reasonable set of X/X truck volume patterns on the roadways. The final X/X 2000 daily truck totals are 1,862 MT and 6,423 HT. These volumes are not significant in the context of the entire model, but they become somewhat more important for analyses that focus on the major through roadways in the region. The through trip tables are shown in Appendix B.

Assignment

The development of revised truck models provides a good opportunity to re-examine the BMC traffic assignment methodology. Many planning agencies have found it necessary to reflect the presence of

trucks in the assignment process, in order to produce more accurate assignments not only of trucks, but all traffic. The most common adjustment is to reflect the presence of truck-restricted roadways. This involves adding a network variable that identifies which roadways prohibit trucks. Some coding schemes are able to deal separately with different kinds of truck restrictions, such as all commercial vehicles vs. trucks over a certain weight, or prohibiting through trucks while permitting local deliveries. However, those schemes require network coding complexities that generally outweigh their value. The consultant recommends a basic scheme in which a link either allows all medium and heavy trucks or prohibits both of them.

As part of this study, BMC staff have added a field to the highway network called NOTRUCK. A value of 2 in this field means that medium and heavy trucks are not permitted to use the link at any time. Any other value means that there is no such restriction. This restriction is activated through special TP+ commands in the HWYLOAD module. These are described further in Chapter 8.

Another assignment refinement is that trucks can be assigned separately from other vehicles and the resulting truck volumes can be maintained separately on each link. This can be of value for computing truck VMT and VHT data for emission calculations and other impact analyses, such as noise. The consultant has included this capability in the new procedures as well.

Finally, the consultant recommends that truck trips be adjusted to represent their true impact on capacity. According to the Highway Capacity Manual and other sources, large trucks "use up" more roadway capacity than other vehicles, due to their large size and slow speeds. Thus, the accuracy of BMC's capacity-restrained assignment should be improved if truck volumes could be temporarily factored upwards by a "passenger car equivalent" (PCE) to represent their disproportional impact on the V/C calculation. TP+ facilitates this calculation and the consultant recommends that it be incorporated into the assignment procedure.

The question remains as to what PCE values to use. A review of the literature and discussions with other planners suggests that the PCE for heavy trucks is in the range of 2.0 - 4.0. Medium trucks perform more like passenger cars and should thus have a smaller PCE. The consultant and staff have agreed that values given in the 2000 Highway Capacity Manual of 1.5 and 2.0 should be used for medium and heavy trucks, respectively. These can be easily modified later, should they prove to be unworkable. The TP+ setups in Chapter 8 show how this is implemented.

BMC performs traffic assignments for five time periods of the day: night, AM peak, midday, PM peak, and evening. This is helpful in modelling system features that vary by time of day (such as HOV operation and reversible roadways) and generally leads to the development of more accurate peak period or peak hour volumes. However, prior BMC analysis has shown that on a regional basis, the difference between a standard daily assignment's volumes and the sum of the five period volumes is not large. Thus, for the purposes of the interim truck model, only a daily assignment procedure is used. For the final model, new time of day factors are provided.

Validation

The interim model described above was applied to year 2000 conditions, using the 1998 zone structure. This included newly developed external station truck volumes and the newly created split of employment by four types: retail, industrial, office, and other as shown in Appendix A. The resulting daily assigned truck volumes were compared to the counts posted in the network, by truck type.

The total error was -1.2% for medium trucks, +94.0% for heavy trucks. The %RMSE values were 76% and 237%, respectively. These do not indicate a high degree of accuracy, although they are somewhat better than the existing model for 2000. In any case, it is clear that this can be improved upon.

The interim model provides a reasonable basis for the subsequent analysis. The development of the interim truck model is complete. This model is then applied for 2000 to develop the truck trip tables to be used as the starting point for the adaptable assignment process. This is described in the next chapter.

5 First Adaptable Runs

Approach

As noted above, the premise of adaptable assignment is that it is possible to systematically compare the traffic counts to the assigned volumes and then use that comparison to adjust the starting trip table for each O/D pair. The resulting O/D volumes will produce assignments that more closely match the counts. However, it is entirely possible that the adjustment for some O/D pairs will counteract the adjustment for other O/D pairs. Thus, the process must be iterated several times until a balance has been achieved and little additional assignment accuracy can be expected. The details of this process are described in reference 4.

Having applied the adaptable assignment procedure to several different models, the consultant has discovered that its use is not a deterministic process. In particular, the appropriate number of iterations must be ascertained by trial and error. Typically, the iterations are increased until the improvement in accuracy between iterations is very small and the trip table changes stabilize.

In addition, the output trip table must be examined carefully to determine how it differs from the input trip table. If these differences can be understood, it should be possible to use them to develop adjustments to the starting model, so that its estimates will better reflect the count data.

The consultant ran various tests of the adaptable assignment process to determine suitable values for its various parameters and options. The best results were achieved by using 10 iterations for medium trucks and 5 iterations for heavy trucks. In both cases, the adapted trip table is finalized after the 5th iteration, so that the external station totals will match the counts. Counts in the Baltimore region are given a higher priority (compared to Washington area counts), so as to try to match them more closely.

Feedback

As noted above, the adaptable assignment process produces a new trip table. The difference between this table and the starting trip table is called the "delta table". In effect, the delta table is an O/D matrix of calibration adjustments that, when added to the starting trip table, produce a table that matches the counts fairly closely. Analysis of this delta table can provide clues as to how to modify the interim model, so as to make it more accurate.

Specifically, the consultant examined the trip end summary of this delta table (separately for medium and heavy trucks). This was then

compared to the land use data to see if there was a systematic employment- or household-based adjustment that would improve the model. None was found.

Next, the consultant cross-tabulated the delta trip ends and the starting (interim model) trip ends by various factors, including truck zone type, jurisdiction, and density code. This analysis was more fruitful and strongly indicated a number of modifications to the truck zone factors. In addition, it suggested a need for jurisdiction- and density code-based adjustment factors.

After several iterations of this analysis, the consultant arrived at some adjustments to the interim trip generation model to make it more suitable. The revised interim model is shown in Table 11.

This revised model incorporates adjustment factors based on the density code and jurisdiction of the zone. In general, these adjustments reduce the number of trips in the more developed areas and in the Washington portion of the network. This is logical -- since the developed areas have more employees, it would make sense that the truck trip rate per employee might be less in those areas. Also, it is clear that the Washington area should have fewer truck trips than the Baltimore area, due to the lower concentration of industrial activity there.

In addition, this analysis indicated that the initially assumed truck zone factors shown in Table 5 were too high. The revised factors, shown in Table 11, suggest that only in the Business District zones are the medium truck trips per employee higher than elsewhere. For heavy trucks, the Intermodal/Transfer and Institutional/Other zones have a higher trip rate. In all cases, the factors for the "Larger" zones equal or exceed those for the "Smaller" zones, which is logical.

The revised interim model estimates 286,000 medium truck trips (249,000 I/I, 35,000 external, 2,000 X/X) and 268,000 heavy truck trips (192,000 I/I, 69,000 external, 7,000 X/X).

The assignment statistics for the revised interim model are improved: total error of 0.9% and 40.0% for medium and heavy trucks, and %RMSE values of 63% and 118%, respectively.

Table 11
Revised Interim Generation Model

$$MT = 0.70 * (0.178 * INDEMP + 0.177 * RETEMP + 0.048 * OFFEMP + 0.069 * HH)$$

$$HT = 0.90 * (0.199 * INDEMP + 0.141 * RETEMP + 0.029 * OFFEMP + 0.068 * HH)$$

Factor for truck zone type:

Type	Scale			
	Larger		Smaller	
	MT	HT	MT	HT
Business District	1.3	1.1	1.2	1.0
Warehouse/Mfgr.	1.0	1.9	1.0	1.8
Intermodal Transfer	1.0	4.3	1.0	3.5
Airport	1.0	1.0	N/A	N/A
Institutional/Other	1.0	2.7	1.0	1.4
Delivery/Medium Truck	1.3	2.0	1.0	1.6

Factor for density code:

Type	MT	HT
Rural	1.4	0.8
Suburban	0.8	0.6
Urban	0.8	1.0
City Center	0.8	0.6

Factor for jurisdiction:

Type	MT	HT
Baltimore City	1.1	1.4
Anne Arundel	1.2	1.2
Baltimore County	1.3	1.2
Carroll	1.3	1.1
Harford	1.5	1.5
Howard	1.1	1.0
D.C.	0.7	0.4
Montgomery	0.8	0.4
Prince George's	1.1	0.8
Frederick	0.6	0.6

6 Final Adaptable Run

Although adaptable assignment helped identify a number of changes that make the interim model more accurate, the resulting accuracy is still not as good as one would like to see. One must recognize the limitations of all relatively simplistic regional travel models, which use fairly basic, available zone-level variables. It is the consultant's experience that *no* travel forecasting model can replicate the millions of individual decisions that take place each day, so as to estimate link-level volumes that match the counts with a very high degree of accuracy. Traffic counts may be somewhat consistent from day to day, but they do include a certain degree of randomness that cannot be reproduced perfectly by a travel model that is limited to relatively simple inputs and relatively simple relationships. However, that observation does not invalidate the use of this model, or any regional travel model, for planning purposes.

As described in Chapter 5, adaptable assignment can be used to "inform" a model, to make it more accurate with respect to the counts. However, no matter how accurate the starting model becomes, the adaptable process will always create a non-zero delta table. This final delta table represents a set of calibration adjustments that are necessary in order to match the counts with a higher degree of accuracy.

This adjustment table becomes an integral part of the model. It is always added to the model output, to become the "final" trip table for assignment purposes. The consultant believes that this method of assignment calibration is superior to most other techniques and produces results that are not only more accurate in the base year, but more credible in the forecast years.

Table 12 presents the final delta trip tables for medium and heavy trucks. The total delta (net difference) is 49,042 trips for medium trucks and 28,724 trips for heavy trucks. The most desirable characteristic of a delta trip table is that it is small, relative to the starting table. For medium trucks, the total delta is 17% of the starting trip table; for heavy trucks, the delta is 11%. Smaller fractions would be preferable, but these are acceptable. Another desirable feature is that the relative delta should be more or less consistent across the region. This is largely the case for medium trucks, but the heavy truck delta shows an interesting pattern that it is small, in absolute value, for Baltimore City and rather large for Harford County. The reasons for this are unclear.

The fact that the external stations have a net delta of zero is not a coincidence. The Fratar step referred to earlier ensures that this will be the case.

Table 12
Final Delta Trip Tables

Date: 6/30/02
Time: 3:49

Baltimore Metropolitan Council Travel Model
2000 Daily Trip Calibration Adjustment Table
Medium Trucks

		Destination District								Total
		1	2	3	4	5	6	7	8	
Origin District	1 BaltCity	4136	159	878	-65	-204	-341	-258	-112	4193
	2 AnnArndl	-599	8221	-315	-52	-27	-1011	-710	332	5839
	3 BaltmrCo	1386	26	10740	-191	722	139	-294	218	12746
	4 Carroll	-58	-46	-223	2193	-2	280	233	197	2574
	5 Harford	-193	-45	672	-8	3629	-14	-39	-15	3987
	6 Howard	-290	-509	39	377	-21	4993	-79	-21	4489
	7 DC Area	-205	-308	-355	162	-44	-208	16405	-252	15195
	8 External	-86	277	162	219	-62	-30	-172	-289	19
Total		4091	7775	11598	2635	3991	3808	15086	58	49042

Table 12 (continued)

Date: 6/30/02
Time: 3:49

Baltimore Metropolitan Council Travel Model
2000 Daily Trip Calibration Adjustment Table
Heavy Trucks

		Destination District								Total
		1	2	3	4	5	6	7	8	
O	1 BaltCity	3600	-1478	3186	-630	-874	-1786	-3137	-2286	-3405
r	2 AnnArndl	-2725	8976	-1019	-282	-417	-666	-747	341	3461
i	3 BaltmrCo	2955	-400	9047	-647	-224	-267	-2137	-777	7550
g	4 Carroll	-612	-281	-615	2400	-177	-150	283	638	1486
i	5 Harford	-924	-383	-232	-174	6913	-207	-636	234	4591
n	6 Howard	-1728	-67	-564	-146	-234	6505	-378	-460	2928
	7 DC Area	-2945	-521	-2262	122	-577	-415	15237	3384	12023
D	8 External	-2298	447	-693	680	325	-387	3356	-1340	90
Total		-4677		6848		4735		11841		28724
			6293		1323		2627		-266	

Table 12 (continued)

Date: 6/30/02
Time: 3:49

Baltimore Metropolitan Council Travel Model
2000 Daily Starting Trip Table
Medium Trucks

		Destination District								
		1	2	3	4	5	6	7	8	Total
O	1 BaltCity	19969	2436	6690	273	516	1061	1089	478	32512
r	2 AnnArndl	2445	23146	2205	209	230	2207	3246	1077	34765
i	3 BaltmrCo	6688	2212	38198	1066	1693	1474	1379	1087	53797
g	4 Carroll	279	212	1064	9357	99	404	690	655	12760
i	5 Harford	514	228	1699	94	12323	114	262	1326	16560
n	6 Howard	1064	2204	1479	401	119	9522	2384	268	17441
	7 DC Area	1093	3256	1373	690	254	2384	77290	12582	98922
D	8 External	460	1076	1090	657	1334	269	12592	1862	19340
Total		32512		53798		16568		98932		286097
			34770		12747		17435		19335	

Table 12 (continued)

Date: 6/30/02
Time: 3:49

Baltimore Metropolitan Council Travel Model
2000 Daily Starting Trip Table
Heavy Trucks

		Destination District								
		1	2	3	4	5	6	7	8	Total
Origin District	1 BaltCity	23126	5326	11275	1241	2286	2890	5848	6248	58240
	2 AnnArndl	5334	6524	3615	601	861	2030	4847	3977	27789
	3 BaltmrCo	11333	3614	13945	1417	2464	2203	4619	5426	45021
	4 Carroll	1232	599	1412	1444	329	441	1228	1412	8097
	5 Harford	2288	856	2463	328	3260	468	1321	2711	13695
	6 Howard	2898	2043	2199	441	474	2898	3161	1755	15869
	7 DC Area	5836	4834	4623	1228	1319	3143	24250	13382	58615
	8 External	6255	3905	5339	1387	2668	1749	13296	6423	41022
Total		58302		44871		13661		58570		268348
			27701		8087		15822		41334	

Table 12 (continued)

Date: 6/30/02
Time: 3:49

Baltimore Metropolitan Council Travel Model
2000 Daily Delta/Starting Trip Ratio
Medium Trucks

		Destination District								
		1	2	3	4	5	6	7	8	Total
Origin District	1 BaltCity	.21	.07	.13	-.23	-.39	-.31	-.23	-.22	.13
	2 AnnArndl	-.23	.36	-.13	-.24	-.11	-.45	-.21	.31	.17
	3 BaltmrCo	.21	.01	.28	-.17	.43	.09	-.20	.20	.24
	4 Carroll	-.20	-.21	-.20	.23	-.01	.69	.34	.30	.20
	5 Harford	-.37	-.19	.40	-.08	.29	-.11	-.14	.00	.24
	6 Howard	-.26	-.22	.03	.94	-.17	.52	-.02	-.07	.26
	7 DC Area	-.18	-.08	-.25	.23	-.16	-.08	.21	-.01	.15
	8 External	-.18	.26	.15	.33	-.04	-.10	.00	-.15	.00
Total		.13	.22	.22	.21	.24	.22	.15	.00	.17

Table 12 (continued)

Date: 6/30/02
Time: 3:49

Baltimore Metropolitan Council Travel Model
2000 Daily Delta/Starting Trip Ratio
Heavy Trucks

		Destination District								Total
		1	2	3	4	5	6	7	8	
O	1 BaltCity	.16	-.27	.28	-.50	-.37	-.61	-.53	-.36	-.05
r	2 AnnArndl	-.50	1.38	-.27	-.46	-.47	-.32	-.14	.09	.12
i	3 BaltmrCo	.26	-.10	.65	-.45	-.08	-.11	-.45	-.13	.17
g	4 Carroll	-.49	-.46	-.43	1.66	-.53	-.33	.23	.45	.18
i	5 Harford	-.39	-.44	-.08	-.52	2.12	-.43	-.47	.09	.34
n	6 Howard	-.59	-.02	-.25	-.32	-.48	2.24	-.11	-.25	.18
	7 DC Area	-.49	-.10	-.48	.10	-.43	-.12	.63	.25	.21
D	8 External	-.36	.11	-.12	.49	.12	-.21	.25	-.20	.00
Total		-.07	.23	.15	.16	.35	.17	.20	.00	.11

It is also clear from these tables that the intra-jurisdictional cells are always positive, while many of the inter-jurisdictional cells are negative. This reflects the tendency of adaptable assignment to add more short trips than long trips. Mechanically, this is because adaptable assignment factors the starting trips to match the counts, and the majority of the trips from any zone tend to go to nearby zones. Thus, the process tends to magnify these close trips. However, this may make some rational sense also, since very short trips tend to be undercounted in trip surveys. The reduction in longer trips suggests that long trip O/D pairs are contributing disproportionately to the links that are initially overestimated.

The average trip length of both types of truck trips is reduced, when the delta table is included, as shown in Table 13. The slight drop in medium truck trip length is typical and is of no great concern. The heavy truck trip length drops more sharply, however. In this case, it is unclear if the implied increase in short trips is rational. However, it is very difficult to say whether this is a problem or not.

Table 13
Starting and Final Trip Lengths

	MT	HT
Starting Trip Table	17.2	35.2
Final Trip Table	16.5	28.1
Percent Change	-4%	-20%

Note: all figures include External and X/X trips.
Starting value represents revised interim model.

It should also be noted that in the delta trip matrix, the individual cell values include fractional amounts of trips (to the nearest 0.01 trip) and in many cases, are negative. Special care must be taken in forecasting to ensure that when these delta values are added to the model's initial estimates, that the resulting value does not become negative for any cell. Such values should be re-set to zero. Also, both delta tables include all matrix cells, including I/I, I/X, X/I, and X/X values. Both the interim model and the delta tables represent 24-hour travel on a typical weekday.

As noted above, the medium and heavy truck delta tables now become an integral part of the truck model. They must always be added to the results of the starting model, in order to produce the final trip table.

Accuracy

As the final step in the development of the truck model, the truck delta tables were added to the tables from the revised interim model and the resulting tables were assigned to the BMC 2000 network. The

assignment procedure was modified from BMC's standard process, so as to:

- 1) maintain medium and heavy truck volumes separately by link,
- 2) prevent medium and heavy trucks from using truck-prohibited links, and
- 3) factor medium truck volumes by 1.5 and heavy truck volumes by 2.0, for the purposes of the V/C calculation

The resulting assigned volumes were compared to the medium and heavy truck counts, producing the reports shown in Tables 14a and 14b (for this purpose, the "heavy truck" count included buses). The total error is -0.4% for medium trucks and +4.3% for heavy trucks, while the %RMSE values are 24% and 33%, respectively. This is a large improvement over both the interim model and the revised interim model, and is substantially better than the MC96 model. It is also slightly better than the overall MC96 validation for *all* vehicles. The MC96 %RMSE for all vehicles was reported as 38.6% for links in the Baltimore area and calculated by the consultant as 59% for the entire BMC modelled area.

There is little difference in the estimated/observed ratio, when stratified by the various fields shown in these reports. The %RMSE values tend to be better (lower) for the higher-type, higher-volume facilities, but this is to be expected.

There is a small discrepancy in the External station volumes that bears clarification. As part of the adaptable assignment process, the external station trip ends are Fratared to match the starting totals, which are in turn derived from counts. Thus, these totals should match very closely. As Table 14a indicates, the external station volumes appear to be underestimated for medium trucks. This is because the BMC assignment process assigns through-trips separately and the through-trips (auto and truck) are output on a separate link volume field. The volume field used to create these reports excludes those through volumes. This explains why the medium truck external station counts appear to be underestimated. For the heavy truck trips, the counts appear to be overestimated. This is because the heavy truck counts at the external stations exclude bus trips, while the other heavy truck counts include them.

The consultant believes that the adaptable assignment process is at least as valid as the count data. The result of this process is a model that both matches the counts and displays reasonable sensitivity to changes. The new model's coefficients and the inclusion of special factors for truck zones should produce more logical and defensible trip patterns. This is a major improvement in accuracy and credibility, compared to the old truck models.

Table 14a
Assignment Report: Medium Trucks

BMC Truck Model Adaptable Evaluation Results 2000, Medium Trucks 06/30/02 15:24:13

County	Count	Vol Est/Obs	%RMSE	Links	Obs VMT	Est VMT	
External	38642	35662	0.92	0.22	84	11590	10693
BaltCity	33369	35149	1.05	0.29	109	8533	9088
AnnArndl	142466	141864	1.00	0.23	205	116588	116850
BaltmrCo	233050	237618	1.02	0.28	300	157323	154760
Carroll	21264	20579	0.97	0.14	76	23653	23050
Harford	49596	48465	0.98	0.19	148	73339	69905
Howard	84486	83182	0.98	0.21	112	73280	70516
Montgomery	31920	32650	1.02	0.27	38	32709	33528
PG	96630	93441	0.97	0.11	60	114678	110130
Frederick	11748	11395	0.97	0.18	22	31641	29973

Vol Class	Count	Vol Est/Obs	%RMSE	Links	Obs VMT	Est VMT	
<= 999	298328	314650	1.05	0.30	943	205526	212208
1000-2499	241071	239880	1.00	0.17	147	252041	245597
2500-4999	203772	185475	0.91	0.11	64	185767	170688

Area Type	Count	Vol Est/Obs	%RMSE	Links	Obs VMT	Est VMT	
Rural	262928	256130	0.97	0.23	543	308376	296305
Suburban	452116	454994	1.01	0.24	529	327389	324452
Urban	19854	20771	1.05	0.20	62	6434	6626
City Ctr	8273	8110	0.98	0.07	20	1135	1110

Roadway Type	Count	Vol Est/Obs	%RMSE	Links	Obs VMT	Est VMT	
Freeway	495442	486058	0.98	0.17	343	497391	481336
>2 Ln Div	40510	43116	1.06	0.17	84	24120	25901
2WCLTL	12016	11735	0.98	0.05	28	8446	8175
Undivided	22074	22620	1.02	0.23	60	11712	11790
Arterial	60579	64741	1.07	0.37	175	18359	19428
Rural Hwy	27288	27498	1.01	0.11	103	31406	30766
Substndrd	28534	29748	1.04	0.42	194	27773	27952
Local	13480	14758	1.09	0.54	76	10282	10737
Ramp 1	372	1077	2.90	1.93	2	119	331
Ramp 2	3586	2326	0.65	0.60	3	1994	1233
Ramp 5	648	666	1.03	0.17	2	142	151
Cent Conn	38642	35662	0.92	0.22	84	11590	10693

Table 14a (continued)

Cong Spd Range	Count	Vol Est/Obs	%RMSE	Links	Obs VMT	Est VMT	
0	708	818	1.16	0.27	3	50	57
5	300	382	1.27	0.27	1	18	23
10	958	1136	1.19	0.22	2	316	374
15	8540	10116	1.18	0.45	8	7040	8848
20	29468	28894	0.98	0.20	58	18798	18064
25	47474	46098	0.97	0.34	133	24267	22812
30	57606	52086	0.90	0.28	92	25192	22781
35	47386	49834	1.05	0.20	103	43491	43780
40	109995	117825	1.07	0.36	361	84960	86874
45	72096	72898	1.01	0.19	100	55796	56195
50	41484	42425	1.02	0.20	51	31476	32122
55	51212	50070	0.98	0.16	26	60005	57314
60	202990	198410	0.98	0.18	153	162662	156404
65	72954	69013	0.95	0.18	63	129263	122845

Cap/Lane Range	Count	Vol Est/Obs	%RMSE	Links	Obs VMT	Est VMT	
500	4854	4664	0.96	0.29	20	1142	1095
750	21751	23635	1.09	0.40	90	11961	12480
1000	1286	1380	1.07	0.19	6	370	399
1250	17808	18927	1.06	0.26	72	6029	6482
1500	85026	88698	1.04	0.48	330	49596	49700
1750	43756	45073	1.03	0.16	97	29012	30128
2000	61610	64107	1.04	0.22	138	64392	65606
2250	468438	457859	0.98	0.17	317	469242	451910
3000	38642	35662	0.92	0.22	84	11590	10693

Totals:

Count	743171.000
Assigned Vol	740005.000
Est/Obs Vol	0.996
RMS Error	28848749.000
Avg RMS Error	158.110
% RMS Error	0.245515
Links	1154.000
Obs. VMT	643334.000
Est. VMT	628493.000
Est/Obs VMT	0.977
Corr Coef R	0.988
Coef Var Rsq	0.977017

Table 14b
Assignment Report: Heavy Trucks

BMC Truck Model Adaptable Evaluation Results 2000, Heavy Trucks 06/30/02 15:24:25

County	Count	Vol Est/Obs	%RMSE	Links	Obs VMT	Est VMT	
External	81970	86649	1.06	0.29	74	24590	25995
BaltCity	70335	74507	1.06	0.54	113	18635	19737
AnnArndl	253600	265473	1.05	0.30	207	211542	220289
BaltmrCo	524324	545674	1.04	0.33	304	410477	415697
Carroll	29700	31521	1.06	0.29	76	33452	36263
Harford	110956	115307	1.04	0.30	148	228482	232736
Howard	188256	193845	1.03	0.21	114	187894	190270
Montgomery	55842	60034	1.08	0.29	38	60038	63884
PG	201516	209841	1.04	0.27	60	289992	281796
Frederick	29286	29260	1.00	0.20	22	81951	80922

Vol Class	Count	Vol Est/Obs	%RMSE	Links	Obs VMT	Est VMT	
<= 999	281833	356923	1.27	0.79	823	178342	225690
1000-2499	200672	216036	1.08	0.43	127	127511	135350
2500-4999	484606	474457	0.98	0.17	130	517198	514709
5000-9999	473826	466315	0.98	0.12	66	618634	594834
10K-19999	104848	98380	0.94	0.09	10	105368	97006

Area Type	Count	Vol Est/Obs	%RMSE	Links	Obs VMT	Est VMT	
Rural	571797	601733	1.05	0.30	547	769114	792169
Suburban	930366	964522	1.04	0.32	529	766229	763215
Urban	32240	33812	1.05	0.39	60	10242	10665
City Ctr	11382	12044	1.06	0.14	20	1468	1540

Roadway Type	Count	Vol Est/Obs	%RMSE	Links	Obs VMT	Est VMT	
Freeway	1136453	1175034	1.03	0.20	349	1327372	1330641
>2 Ln Div	65082	74125	1.14	0.55	86	45589	46708
2WCLTL	13912	16061	1.15	0.35	28	9652	11460
Undivided	27384	27951	1.02	0.68	60	14244	14741
Arterial	118467	120601	1.02	0.52	179	36375	37449
Rural Hwy	28234	33231	1.18	0.45	103	33707	38255
Substndrd	43532	47445	1.09	0.54	194	36206	42281
Local	23280	27619	1.19	0.78	76	15994	18570
Ramp 1	192	1052	5.48	4.49	2	61	343
Ramp 2	6961	2089	0.30	0.80	3	3193	1091
Ramp 5	318	254	0.80	0.21	2	70	55
Cent Conn	81970	86649	1.06	0.29	74	24590	25995

Table 14b (continued)

Cong Spd Range	Count	Vol Est/Obs	%RMSE	Links	Obs VMT	Est VMT	
0	1777	1884	1.06	0.10	3	114	122
5	1365	1458	1.07	0.07	1	82	88
10	1019	2817	2.76	2.16	2	330	886
15	17968	21974	1.22	0.31	9	17582	20947
20	60334	60363	1.00	0.49	63	36844	38846
25	81007	89143	1.10	0.47	132	40696	45864
30	109144	112654	1.03	0.40	81	42217	43676
35	95505	95624	1.00	0.38	103	93700	89652
40	179433	193889	1.08	0.57	364	130757	138154
45	130939	141424	1.08	0.30	101	97258	107155
50	84075	95995	1.14	0.44	53	105340	110105
55	180516	175936	0.97	0.14	30	197453	184878
60	394901	409354	1.04	0.22	150	361676	366463
65	207802	209596	1.01	0.14	64	423004	420753

Cap/Lane Range	Count	Vol Est/Obs	%RMSE	Links	Obs VMT	Est VMT	
500	6676	7113	1.07	0.34	20	1654	1746
750	44070	45431	1.03	0.68	94	21220	22684
1000	920	877	0.95	0.19	6	282	267
1250	34486	37717	1.09	0.39	72	10794	12041
1500	134734	139779	1.04	0.73	330	69548	75630
1750	68606	78477	1.14	0.76	99	50721	55488
2000	88239	99871	1.13	0.42	138	98019	105860
2250	1086084	1116197	1.03	0.19	323	1270225	1267878
3000	81970	86649	1.06	0.29	74	24590	25995

Totals:

Count	1545785.000
Assigned Vol	1612111.000
Est/Obs Vol	1.043
RMS Error	223161748.000
Avg RMS Error	439.371
% RMS Error	0.328579
Links	1156.000
Obs. VMT	1547053.000
Est. VMT	1567589.000
Est/Obs VMT	1.013
Corr Coef R	0.984
Coef Var Rsq	0.968044

7 Forecasting

2025 Run

The consultant believes that a model is not complete until it has been used to make a forecast. As the final step in the development of the truck model, BMC staff provided the consultant with data and setups for a 2025 forecast, labelled "SP25". The consultant applied the model to that scenario, with the results as shown in Table 15.

Table 15
2025 Forecast Summary – Additive Delta

	2000		2025		% Change	
	MT	HT	MT	HT	MT	HT
Truck Trips	334,700	296,600	425,300	428,800	27%	45%
Avg. Trip Length (mi.)	9.1	19.6	10.3	22.3	13%	14%
Truck VMT (000)	3,036.2	5,826.7	4,369.3	9,548.4	44%	64%

Notes:

Includes validation adjustments.

VMT includes centroid connector VMT.

Includes I/I, External, and X/X trips for entire BMC network.

As this table shows, not only are the number of truck trips growing, but their average trip length is growing also. This produces a noticeable increase in truck VMT in 2025. This is equivalent to an annual average growth rate of 1.5% for medium trucks, and 2.0% for heavy trucks. The final medium and heavy truck trip tables, including the additive calibration adjustment, are shown in Table 16.

Multiplicative Delta

In the consultant's experience with the adaptable assignment process, reasonable results have been obtained with the method of application indicated above: the delta table, expressed in units of trips, is treated as an *additive* calibration adjustment and is added to all forecast year trip tables. However, BMC staff wanted to investigate an alternative method of application. Instead of creating an additive delta by subtracting the starting table from the final table, this involves creating a *multiplicative* delta. In this case, the delta table is the ratio of the final table divided by the starting table (thus, the cell values are factors). In application, this table of factors is multiplied by the model's initial table to create the final trip table.

Table 16
2000 and 2025 Trip Tables

Date: 6/30/02
Time: 16:11

Baltimore Metropolitan Council Travel Model
2000 Final Daily Trip Table (w/Add. Calib. Adj.)
Medium Trucks

		Destination District								
		1	2	3	4	5	6	7	8	Total
Origin District	1 BaltCity	24089	2618	7525	195	299	711	828	370	36635
	2 AnnArndl	1898	31349	1854	152	218	1158	2519	1387	40535
	3 BaltmrCo	7974	2267	48859	833	2486	1546	1071	1376	66412
	4 Carroll	193	162	845	11593	81	667	922	857	15320
	5 Harford	287	199	2418	82	15916	85	213	1329	20529
	6 Howard	757	1725	1499	802	95	14465	2309	240	21892
	7 DC Area	818	2947	1000	891	196	2191	93658	12339	114040
	8 External	351	1355	1250	888	1270	238	12426	1561	19339
Total		36367		65250		20561		113946		334702
			42622		15436		21061		19459	

Date: 6/30/02
Time: 16:11

Baltimore Metropolitan Council Travel Model
2000 Final Daily Trip Table (w/Add. Calib. Adj.)
Heavy Trucks

		Destination District								
		1	2	3	4	5	6	7	8	Total
O	1 BaltCity	26659	3842	14471	633	1379	1103	2708	3972	54767
r	2 AnnArndl	2542	15462	2538	313	461	1358	4109	4394	31177
i	3 BaltmrCo	14208	3209	22866	744	2289	1864	2484	4760	52424
g	4 Carroll	618	318	799	3839	114	291	1530	2028	9537
i	5 Harford	1342	465	2283	113	10154	219	673	2997	18246
n	6 Howard	1158	1985	1638	294	232	9384	2763	1306	18760
	7 DC Area	2737	4361	2317	1379	710	2777	39377	16892	70550
D	8 External	3930	4354	4647	2071	2986	1365	16663	5076	41092
Total		53194		51559		18325		70307		296553
			33996		9386		18361		41425	

Date: 6/30/02
Time: 16:11

Baltimore Metropolitan Council Travel Model
2025 Final Daily Trip Table (w/Add. Calib. Adj.)
Medium Trucks

		Destination District								
		1	2	3	4	5	6	7	8	Total
O	1 BaltCity	26886	3216	9124	350	617	1406	1397	637	43633
r	2 AnnArndl	2560	33547	2373	257	305	2245	3952	1984	47223
i	3 BaltmrCo	9624	2762	53062	1275	2890	2214	1751	1876	75454
g	4 Carroll	347	266	1298	13723	123	856	1310	1298	19221
i	5 Harford	614	293	2817	134	19615	171	356	2209	26209
n	6 Howard	1396	2678	2152	1004	162	18791	3660	489	30332
	7 DC Area	1410	4215	1731	1293	352	3530	119788	19972	152291
D	8 External	616	1946	1757	1327	2147	487	20051	2578	30909
Total		43453		74314		26211		152265		425272
			48923		19363		29700		31043	

Date: 6/30/02
Time: 16:11

Baltimore Metropolitan Council Travel Model
2025 Final Daily Trip Table (w/Add. Calib. Adj.)
Heavy Trucks

		Destination District								
		1	2	3	4	5	6	7	8	Total
O	1 BaltCity	31161	5814	17582	1482	2575	2963	5906	7789	75272
r	2 AnnArndl	4622	17005	3826	642	964	2538	5986	6816	42399
i	3 BaltmrCo	17444	4482	25468	1756	3345	3180	4931	7773	68379
g	4 Carroll	1483	651	1813	4390	387	652	2283	3170	14829
i	5 Harford	2534	954	3355	400	11734	603	1627	5312	26519
n	6 Howard	3040	3067	2961	657	602	11026	4670	3078	29101
	7 DC Area	5950	6128	4892	2197	1617	4733	48081	27839	101437
D	8 External	7735	6741	7614	3206	5289	3115	27588	9593	70881
Total		73969		67511		26513		101072		428817
			44842		14730		28810		71370	

Date: 6/30/02
 Time: 16:11

Baltimore Metropolitan Council Travel Model
 2025/2000 Daily Trip Ratio
 Medium Trucks

		Destination District								
		1	2	3	4	5	6	7	8	Total
Origin District	1 BaltCity	1.12	1.23	1.21	1.79	2.06	1.98	1.69	1.72	1.19
	2 AnnArndl	1.35	1.07	1.28	1.69	1.40	1.94	1.57	1.43	1.16
	3 BaltmrCo	1.21	1.22	1.09	1.53	1.16	1.43	1.63	1.36	1.14
	4 Carroll	1.80	1.64	1.54	1.18	1.52	1.28	1.42	1.51	1.25
	5 Harford	2.14	1.47	1.17	1.63	1.23	2.01	1.67	1.66	1.28
	6 Howard	1.84	1.55	1.44	1.25	1.71	1.30	1.59	2.04	1.39
	7 DC Area	1.72	1.43	1.73	1.45	1.80	1.61	1.28	1.62	1.34
	8 External	1.75	1.44	1.41	1.49	1.69	2.05	1.61	1.65	1.60
Total		1.19		1.14		1.27		1.34		1.27
			1.15		1.25		1.41		1.60	

Date: 6/30/02
 Time: 16:11

Baltimore Metropolitan Council Travel Model
 2025/2000 Daily Trip Ratio
 Heavy Trucks

		Destination District								
		1	2	3	4	5	6	7	8	Total
Origin District	1 BaltCity	1.17	1.51	1.21	2.34	1.87	2.69	2.18	1.96	1.37
	2 AnnArndl	1.82	1.10	1.51	2.05	2.09	1.87	1.46	1.55	1.36
	3 BaltmrCo	1.23	1.40	1.11	2.36	1.46	1.71	1.99	1.63	1.30
	4 Carroll	2.40	2.05	2.27	1.14	3.39	2.24	1.49	1.56	1.55
	5 Harford	1.89	2.05	1.47	3.54	1.16	2.75	2.42	1.77	1.45
	6 Howard	2.63	1.55	1.81	2.23	2.59	1.17	1.69	2.36	1.55
	7 DC Area	2.17	1.41	2.11	1.59	2.28	1.70	1.22	1.65	1.44
	8 External	1.97	1.55	1.64	1.55	1.77	2.28	1.66	1.89	1.72
Total		1.39	1.32	1.31	1.57	1.45	1.57	1.44	1.72	1.45

Mathematically and mechanically, both approaches are feasible. The selection of a preferred approach depends partly on how the delta table is perceived. If it does in fact reflect a basic "error" in the model and is therefore somehow related to the employment and/or households, then the multiplicative approach makes sense. This method says that the difference represented by the delta matrix is a *relative* error and should be modified in the forecast year. That is, if the estimate is, say, 6% high in the base year, it will be 6% high in the forecast year, and the future estimate must be divided by 1.06 to compensate.

However, if the error represented by the delta table is due to essentially random causes, then an additive delta is probably more appropriate. In this case, the delta is thought not to be related to employment or households and thus should not change when those variables change in the future.

Another issue involves round-off error. BMC has been following the practice of rounding off trip table values to integers prior to assignment, and the consultant has done so as well. However, integerizing the trips at this stage can cause problems with an additive delta trip table in forecasting. This is because there are many O/D cells that have 1 trip in the base year. For some of these cells, the adaptable process computed a delta value between 0 and -1 (e.g., -0.65). In the base year, this results in a small net value (0.35 in this example), which rounds to zero. However, in a forecast year, it is entirely possible (and actually quite common) for many of these 1-trip cells to become zero after rounding. This can occur as the result of very slight changes in trip patterns, accompanied by the vagaries of bucket rounding. Applying an additive delta of -0.65 then results in a net value of -0.65, which rounds to -1. Although TP+ *can* assign trip table cells which are negative, some of the assignment features (e.g., subarea windowing) do not work properly with such cells. In order to preserve that functionality, the consultant suggests that negative cells be re-set to zero, prior to loading. However, re-setting these cells to zero will not preserve the overall trip table totals (changing 10,000 trip table cells from -1 to 0 effectively "manufactures" 10,000 extra trips).

In order to evaluate both techniques, the consultant performed another 2025 run, this time using a multiplicative table of delta factors. The results are summarized in Table 17 and the final trip tables are shown in Table 18. Table 19 lists the 2000 count, 2000 assigned volume, and 2025 assigned volume from both methods, for a few selected links.

Table 17
2025 Forecast Summary – Multiplicative Delta

	2000		2025		% Change	
	MT	HT	MT	HT	MT	HT
Truck Trips	334,700	296,600	403,300	395,400	20%	33%
Avg. Trip Length	9.1	19.6	9.9	22.6	9%	15%
Truck VMT	3,036.2	5,826.7	3,998.7	8,943.0	32%	53%

Includes validation adjustment.

Comparing Tables 17 and 15 indicates that the multiplicative method forecasts about 6-8% fewer 2025 truck trips and about 7% less truck VMT than does the additive method. Comparing Tables 18 and 16 does not suggest substantial differences between the two methods at the jurisdictional level. Comparing the volumes in Table 19 shows that in a few cases, the multiplicative method forecasts link volumes that are noticeably lower than the additive method, but for the most part, they are similar.

One of the consultant's concerns with the multiplicative method is the potential for large distortion of individual cells of the trip table. However, examination of the resulting values indicated that this has not occurred.

Although the consultant's prior experience with adaptable assignment has always used the additive method, there is a concern in this particular case that this could slightly overestimate future truck volumes, due to the rounding problems noted above. Thus, the consultant recommends that BMC use the multiplicative method for forecasting. The setups in Chapter 8 reflect this approach.

Table 18
2025 Trip Tables – Multiplicative Delta

Date: 6/30/02
Time: 17:22

Baltimore Metropolitan Council Travel Model
2025 Final Daily Trip Table (w/Mult. Calib. Adj.)
Medium Trucks

		Destination District								
		1	2	3	4	5	6	7	8	Total
Origin District	1 BaltCity	24438	2342	7140	331	604	1301	1380	615	38151
	2 AnnArndl	2058	29336	1960	248	262	2264	3556	2083	41767
	3 BaltmrCo	7341	2165	47595	1128	2215	1923	1663	1846	65876
	4 Carroll	335	263	1142	13594	120	771	1076	1351	18652
	5 Harford	596	257	2138	125	19981	162	348	2177	25784
	6 Howard	1276	2697	1863	706	152	20238	3409	463	30804
	7 DC Area	1378	3748	1656	1035	349	3294	120733	19723	151916
	8 External	596	1972	1761	1370	2005	458	19754	2455	30371
Total		38018		65255		25688		151919		403321
			42780		18537		30411		30713	

Date: 6/30/02
Time: 17:22

Baltimore Metropolitan Council Travel Model
2025 Final Daily Trip Table (w/Mult. Calib. Adj.)
Heavy Trucks

		Destination District								
		1	2	3	4	5	6	7	8	Total
O	1 BaltCity	28901	4637	12458	1274	2456	2615	5562	6686	64589
r	2 AnnArndl	4153	9104	3354	639	926	2411	5380	7386	33353
i	3 BaltmrCo	12661	3911	16941	1417	2884	2652	4890	7616	52972
g	4 Carroll	1245	649	1417	2733	387	614	1894	3412	12351
i	5 Harford	2396	939	2860	399	11480	595	1609	5580	25858
n	6 Howard	2711	2914	2517	587	606	10140	4406	2808	26689
	7 DC Area	5607	5505	4821	1926	1598	4315	50812	31732	106316
D	8 External	6628	7266	7449	3402	5608	2893	31160	8853	73259
Total		64302		51817		25945		105713		395387
			34925		12377		26235		74073	

Table 19
2025 Forecast – Link Data

Medium Trucks

Road	A Node	B Node	2000 Count	2000 Volume	2025 "A" Volume	2025 "M" Volume
I-95, N of MD 24 (SB)	9587	9555	1980	1940	2226	2171
I-95, N of MD 24 (NB)	9646	9588	1980	1948	2211	2195
I-695, S of I-70 (Inner Loop)	7779	7862	2330	2420	3972	3996
I-695, S of I-70 (Outer Loop)	7861	7783	2330	2440	4039	4198
Dundalk Ave, N of Broening Hwy (2-way)	8446	8453	234	238	145	74
MD 30, S of Houcksville Rd (2-way)	8746	8748	644	558	525	463
Mulberry St, W of MLKJr (EB)	2791	3046	265	269	400	239
Franklin St, W of MLKJr (WB)	2795	2792	355	355	446	329

Heavy Trucks

Road	A Node	B Node	2000 Count*	2000 Volume	2025 "A" Volume	2025 "M" Volume
I-95, N of MD 24 (SB)	9587	9555	8460	8277	10495	10686
I-95, N of MD 24 (NB)	9646	9588	8460	8322	10609	11037
I-695, S of I-70 (Inner Loop)	7779	7862	5334	6354	12141	11956
I-695, S of I-70 (Outer Loop)	7861	7783	5334	6422	12695	12630
Dundalk Ave, N of Broening Hwy (2-way)	8446	8453	444	355	270	199
MD 30, S of Houcksville Rd (2-way)	8746	8748	1022	933	703	595
Mulberry St, W of MLKJr (EB)	2791	3046	205	212	559	267
Franklin St, W of MLKJr (WB)	2795	2792	306	316	682	427

* Includes buses.

Note: "A" volumes are based on the additive method, "M" volumes are based on the multiplicative method.

8 Final Model

The final recommended truck model includes the following components:

- trip generation model (as described in Table 11)
- trip distribution model (F factors as calculated by Table 10 and as displayed in Figure 4 and Table 21)
- procedure to calculate external trips (Figure 3)
- base year through trip table (Appendix B)
- calibration adjustment tables ("delta tables")
- truck-sensitive assignment process

Figure 5 contains the TP+ setups used to apply the new truck model. This consists of a trip generation setup, a trip distribution setup, and a daily assignment setup, indicating the changes necessary to incorporate the new truck trip tables. The final F factors are shown in Table 21 (these are the same as the interim F factors, as shown previously in Figure 4). As developed for this project, the new truck model estimates average weekday trips for a 24-hour period.

There is no specific process for forecasting through truck trips. The consultant recommends that BMC staff develop a setup to Fratar the consultant's through-trips. It should also be clear that BMC must adjust its current through trip table to remove medium and heavy truck trips.

In order to split these trips by period for the period-based assignments, the consultant recommends the use of a revised set of factors, derived from Reference 2. This uses data for "6+ tire single unit" vehicles for medium trucks and "combination vehicles" for heavy trucks. These factors are shown in Table 20. These factors have not been validated at the link level. A comparison of these factors with the existing values (shown in Table 3) indicates that the new factors are lower for the AM and PM peak periods, considerably higher for Midday, and about the same for Night and Evening.

Table 20
Recommended Truck Time of Day Factors

Period	MT	HT
Night (12 M - 6 AM)	6.5%	13.3%
AM Peak (6 - 10)	27.3	22.5
Midday (10 AM - 3 PM)	36.0	32.6
PM Peak (3 - 7)	22.9	18.3
Evening (7 PM - 12 M)	7.3	13.3

Table 21
Final Truck F Factors

Time	MT F	HT F	Time	MT F	HT F	Time	MT F	HT F
1	1202604	3269017	41	21.0	24296.4	81	2.8	9890.5
2	155627	1309356	42	19.6	23535.8	82	2.7	9731.6
3	47056	766685	43	18.3	22816.0	83	2.6	9577.1
4	20139	524443	44	17.1	22134.0	84	2.5	9426.9
5	10427	390640	45	16.0	21487.0	85	2.4	9280.8
6	6089	307084	46	15.0	20872.6	86	2.4	9138.6
7	3864	250546	47	14.0	20288.4	87	2.3	9000.2
8	2606	210058	48	13.2	19732.3	88	2.2	8865.4
9	1841	179811	49	12.4	19202.5	89	2.1	8734.2
10	1349	156465	50	11.7	18697.2	90	2.1	8606.3
11	1019	137968	51	11.0	18214.8	91	2.0	8481.7
12	788	122998	52	10.4	17753.9	92	1.9	8360.2
13	622	110665	53	9.9	17313.0	93	1.9	8241.8
14	500	100353	54	9.3	16891.1	94	1.8	8126.2
15	408	91617	55	8.8	16486.9	95	1.8	8013.5
16	337	84135	56	8.4	16099.4	96	1.7	7903.5
17	282	77665	57	7.9	15727.6	97	1.7	7796.1
18	238	72021	58	7.6	15370.7	98	1.6	7691.3
19	203	67060	59	7.2	15027.7	99	1.6	7588.9
20	175	62670	60	6.8	14698.0	100	1.5	7488.9
21	151	58761	61	6.5	14380.8	101	1.5	7391.2
22	132	55261	62	6.2	14075.4	102	1.4	7295.7
23	116	52112	63	5.9	13781.2	103	1.4	7202.3
24	102	49265	64	5.6	13497.7	104	1.3	7111.0
25	90	46681	65	5.4	13224.3	105	1.3	7021.8
26	81	44325	66	5.2	12960.4	106	1.3	6934.5
27	72	42171	67	4.9	12705.7	107	1.2	6849.1
28	65	40195	68	4.7	12459.6	108	1.2	6765.5
29	58	38375	69	4.5	12221.8	109	1.2	6683.7
30	53	36696	70	4.3	11991.9	110	1.1	6603.6
31	47.9	35141.5	71	4.2	11769.5	111	1.1	6525.2
32	43.6	33699.2	72	4.0	11554.2	112	1.1	6448.4
33	39.9	32357.8	73	3.8	11345.7	113	1.1	6373.1
34	36.5	31107.5	74	3.7	11143.7	114	1.0	6299.5
35	33.5	29939.7	75	3.5	10948.0	115	1.0	6227.2
36	30.8	28846.8	76	3.4	10758.3	116	1.0	6156.5
37	28.4	27822.2	77	3.3	10574.2	117	1.0	6087.1
38	26.3	26859.8	78	3.2	10395.7	118	0.9	6019.1
39	24.3	25954.5	79	3.0	10222.3	119	0.9	5952.4
40	22.6	25101.4	80	2.9	10054.0	120	0.9	5887.1

Figure 5 TP+ Setups

```
zones=1326
inzones='1-1284'
exzones='1285-1326'

;-----
run pgm=matrix

; Distance to nearest external station
; (input to truck model)

; input off-peak highway skim
filei mati[1] = sp0011.dat

; skip entire calculation for external stations
if (i > @zones@) continue

; get distance matrix; exclude internal zones
mw[1] = mi.1.SOVDist, exclude = @inzones@

; Fill zero cells with large value.
jloop
  if (mw[1] < 0.01) mw[1] = 9999.
endjloop

; "Nearest" zone is the one with the minimum distance.
nearest = rowmin(1)

  print list = i(5.0),nearest(7.2)  file = tkextdst.dat  print=y
endrun
;-----
run pgm=tripgen
;
; Truck Trip Generation
; Purposes: Medium Truck (FHWA F5, 6 tire, 2 axle) and
; Heavy Truck (FHWA F6-F13, 3+ axle)
; Purpose 1 = MT I/I, 2 = HT I/I, 3 = MT External, 4 = HT Ext

; Input Zonal Data
;   Type 2
;   z      1998 TAZ (2-5)
;   rpd    RPD (6-10)
;   pop    Population (11-16)
;   hh     Households (17-22)
;   gq     Persons in Group Quarters (23-26)
;   lf     Labor Force (27-31)
;   te     Total Employment (32-36)
;   sche   School Employment (K-12) (37-41)
;   re     Retail Employment (42-46)
;   nre    Non-Retail Employment (47-51); nre = off + ind + oth
;   off    Office Employment (52-56)
;   ind    Industrial Employment (57-61)
;   oth    Other NRE Employment (62-66)
;   dc     1998 TAZ Density Code (67-68): 1-Rural, 2-Suburban, 3-Urban,
;         4-City Center; Updated regularly

;
;   Ext Sta Vols
;   xmt    External MT Volume (2-way)
```

```
;      xht      External HT Volume (2-way)
;
;      Truck Zones
;      tztype   Truck Zone Type Code (1-12)
;
zdati[1]=..\sp0008.dat, select=2,1, z=2-5, rpd=6-10, pop=11-16, hh=17-22,
                        gg=23-26,
                        lf=27-31, te=32-36, sche=37-41, re=42-46,
                        nre=47-51, off=52-56, ind=57-61,
                        oth=62-66, dc=67-68

; Truck external volumes and external share (0-100%) (100-PCTEXT is
; the Through share)
zdati[3]=tkextvol.prn, z=#1, xmt=#2, xht=#3, pctextmt=#4, pctextht=#5

; "Truck Zones"
zdati[4]=tkzones.prn, z=#1, tztype=#2

; Distance to nearest external station (created above)
zdati[5]=tkextdst.dat, z=#1, extdist=#2

; Output P/A file
pao=sp0010.trk form=8.0 list= z(5.0), p[1], a[1], p[2], a[2], p[3], a[3],
                        p[4], a[4] print=y

zones = @zones@

; Trip Rate Lookup Table
lookup name=trate,
      lookup[1]=1, result=2,          ;MT
      lookup[2]=1, result=3,          ;HT
      list=y,
;
      r=' 1   0.178  0.199',          ; Ind Emp
        ' 2   0.177  0.141',          ; Ret Emp
        ' 3   0.048  0.029',          ; Off Emp
        ' 4   0.069  0.068'          ; HH

; Truck Zone Factor Lookup Table
lookup name=tznfac,
      lookup[1]=1, result=2,          ; MT
      lookup[2]=1, result=3,          ; HT
      list=y,
;
      r=' 1   1.3  1.1',              ;Bus Dist,   Large
        ' 2   1.0  1.9',              ;Whse/Mfgr,  Lg
        ' 3   1.0  4.3',              ;Inter/Trans, Lg
        ' 4   1.0  1.0',              ;Airport,    Lg
        ' 5   1.0  2.7',              ;Inst/Othr,  Lg
        ' 6   1.3  2.0',              ;Exp/Pkg,    Lg
        ' 7   1.2  1.0',              ;Bus Dist,   Small
        ' 8   1.0  1.8',              ;Whse/Mfgr,  Sm
        ' 9   1.0  3.5',              ;Inter/Trans, Sm
        '10   1.0  1.0',              ;(N/A)
        '11   1.0  1.4',              ;Inst/Othr,  Sm
        '12   1.0  1.6'              ;Exp/Pkg,    Sm

; Density Code adjustment table
lookup name=dcfac,
      lookup[1]=1, result=2,          ; MT
      lookup[2]=1, result=3,          ; HT
      list=y,
```

```
;
      MT   HT
r=' 1  1.4 0.8',      ;Rural
   ' 2  0.8 0.6',      ;Suburban
   ' 3  0.8 1.0',      ;Urban
   ' 4  0.8 0.6'       ;City Center

; Jurisdictional Factor Lookup Table
lookup name=jurfac,
      lookup[1]=1, result=2,      ; MT
      lookup[2]=1, result=3,      ; HT
list=y,
;
      MT   HT
r=' 1  1.1 1.4',      ;Balt City
   ' 2  1.2 1.2',      ;Anne Arundel
   ' 3  1.3 1.2',      ;Balt Co
   ' 4  1.3 1.1',      ;Carroll
   ' 5  1.5 1.5',      ;Harford
   ' 6  1.1 1.0',      ;Howard
   ' 7  0.7 0.4',      ;DC
   ' 8  0.8 0.4',      ;Montgomery
   ' 9  1.1 0.8',      ;PG
  '10  0.6 0.6'       ;Frederick

; Apply equations to internal zones
if (i=@inzones@)
  mtp = 0.70 * (trate(1,1)*ind + trate(1,2)*re + trate(1,3)*off + trate(1,4)*hh)
  htp = 0.90 * (trate(2,1)*ind + trate(2,2)*re + trate(2,3)*off + trate(2,4)*hh)

; "Truck zone" adjustments
if (tztype > 0)
  mtp = mtp * tznfac(1,tztype)
  htp = htp * tznfac(2,tztype)
endif

; Density Code adjustments
if (dc > 0)
  mtp = mtp * dcfac(1,dc)
  htp = htp * dcfac(2,dc)
endif

; Jurisdictional adjustments
if (rpd > 0)
  jur = int(rpd/100)
  mtp = mtp * jurfac(1,jur)
  htp = htp * jurfac(2,jur)
endif

; Apply external trip end share model.
; External share is a declining function of the zone's distance to the
; nearest cordon station (in miles). This particular model is an
; amalgam of the Berks Co, PA purpose-specific models, modified
; to produce the correct number of BMC external trips in 2000. Use a
; different model for MT and HT.
extpctm = 0.0
extpcth = 0.0
if (extdist > 0)
  extpctm = 0.919 * exp(-1.2 * ln(extdist))
  extpcth = 0.602 * exp(-0.5 * ln(extdist))
endif
extpctm = max(min(extpctm,1.0),0)
extpcth = max(min(extpcth,1.0),0)
intpctm = 1.0 - extpctm
```

```
intpcth = 1.0 - extpcth

; Apply internal trip end shares; set A's equal to P's
p[1] = mtp * intpctm
p[2] = htp * intpcth
a[1] = p[1]
a[2] = p[2]

; Define all external trip ends as "Productions" at the internal
; zones and "Attractions" at the external stations. Calculate
; these (initially) for internal zones as what's left over
; after the above calculation. Multiply by 2 because we're
; putting external P's and external A's in the same column.
p[3] = 2 * mtp * extpctm
p[4] = 2 * htp * extpcth

endif

; External trip ends. These are the input cordon volumes, which
; we then multiply by the External share. These are defined as
; Attractions, at the external stations.
if (i=@exzones@)
  p[1] = 0
  p[2] = 0
  p[3] = 0
  p[4] = 0
  a[1] = 0
  a[2] = 0
  a[3] = xmt * pctextmt * 0.01
  a[4] = xht * pctextht * 0.01
endif

; Debug
if (i = 63,100,117,200,300)
  print list=i(4), form=6, list=' IRO emp, HH: ',ind,re,off,
  hh,'\n',form=7.2,list=' Tot TE: ',mtp,htp,' Dist to Ext, ext %s: ',
  extdist,extpctm(8.4),extpcth(8.4),'\n',
  list=' MTPII,HTPII: ',p[1],p[2],'\n'
endif

; Normalize the external Productions at the internal zones so that
; their total matches the external Attractions at the external
; stations. This keeps the external station volumes intact.
phase=adjust
p[3] = p[3] * a[3][0]/p[3][0]
p[4] = p[4] * a[4][0]/p[4][0]

endphase

endrun



---



run pgm=tripdist

; Truck Trip Distribution
; Distribute all trips on uncongested skims
; Purposes: Medium Truck (FHWA F5, 6 tire, 2 axle) and
; Heavy Truck (FHWA F6-F13, 3+ axle)
; Purpose 1 = MT I/I, 2 = MT External

; Skims
mati[1]=sp0011.dat
```

```
; Trip ends
zdati[1]=sp0010.trk z=#1,p1=#2,a1=#3,p2=#4,a2=#5,p3=#6,a3=#7,p4=#8,a4=#9

; Output
mato[1]=tempmt.trp, mo=1-2
;
; Maximum 99 iterations, unless RMSE for all purposes is under 25
; (same as for other BMC TD models)
maxiters=99
maxrmse=25
;
;Set productions and attractions
setpa p[1]=p1 p[2]=p3
setpa a[1]=a1 a[2]=a3
;
;Look up friction factors
lookup file=mtrkff.dat name=ff,
      lookup[1]=1, result=2,
      lookup[2]=1, result=2,
      interpolate=y,
      fail=1200000,0.5,0
;
;Distribute trips on skim time excluding HOV facilities
gravity purpose=1, los=mi.01.01, ffactors=ff
gravity purpose=2, los=mi.01.01, ffactors=ff
;
;Perform bucket rounding
bucket1=rowfix(1)
bucket2=rowfix(2)
;
endrun
;-----
run pgm=tripdist

; Purpose 1 = HT I/I, 2 = HT External

; Skims
mati[1]=sp0011.dat

; Trip ends
zdati[1]=sp0010.trk z=#1,p1=#2,a1=#3,p2=#4,a2=#5,p3=#6,a3=#7,p4=#8,a4=#9

; Output
mato[1]=tempht.trp, mo=1-2
;
; Maximum 99 iterations, unless RMSE for all purposes is under 25
; (same as for other BMC TD models)
maxiters=99
maxrmse=25
;
;Set productions and attractions
setpa p[1]=p2 p[2]=p4
setpa a[1]=a2 a[2]=a4
;
;Look up friction factors
lookup file=htrkff.dat name=ff,
      lookup[1]=1, result=2,
      lookup[2]=1, result=2,
      interpolate=y,
      fail=3200000,5000,0
;
;
```

```
;Distribute trips on skim time excluding HOV facilities
gravity purpose=1, los=mi.01.01, ffactors=ff
gravity purpose=2, los=mi.01.01, ffactors=ff
;
;Perform bucket rounding
bucket1=rowfix(1)
bucket2=rowfix(2)
;
endrun
;-----
run pgm=matrix

    id = "2000 Trucks: balance trips, add X/X, and do TLFs

; Input files: trips, skims, X/X
mati[1] = tempmt.trp
mati[2] = tempht.trp
mati[3] = sp0011.dat
mati[4] = sp00tkxx.trp

mato    = sp00trk.trp, mo=6-9, name = MTrk, HTrk, MTXX, HTXX

; Sum II and Ext trips.
mw[1] = mi.1.1 + mi.1.2          ; MT
mw[2] = mi.2.1 + mi.2.2          ; HT

; Transpose
mw[4] = mi.1.1.t + mi.1.2.t
mw[5] = mi.2.1.t + mi.2.2.t

; Sum and round. Insert X/X trips as tables 3 (MT) and 4 (HT).
mw[6] = 0.5 * (mw[1] + mw[4])
mw[7] = 0.5 * (mw[2] + mw[5])
rnd6 = rowfix(6)
rnd7 = rowfix(7)
mw[8] = mi.4.1
mw[9] = mi.4.2

; Time (w/o barrier penalties).
mw[3] = mi.3.1

; TLF (still in P/A format, excluding X/X).
frequency basemw=3, valuemw=1, range=0-90-2,
title='Est 2000 Medium Truck vs. Hwy Time'

frequency basemw=3, valuemw=2, range=0-90-2,
title='Est 2000 Heavy Truck vs. Hwy Time'

endrun
*del temp*.trp

-----

run pgm=matrix

; BMC Truck Model
; Calibration final production run w/mult. delta
; final.s

id = "Apply delta adjustments

mati[1] = ..\int\sp00trk.trp
```

```
mati[2] = ..\xx\sp00tkxx.trp
mati[3] = delta.fac

mato    = sp00trk.adj, mo = 1-4, name=MTrk, HTrk, MTXX, HTXX

; Apply multiplicative deltas and bucket round.
mw[1] = mi.1.1 * mi.3.1      ; MT int+ext
mw[2] = mi.1.2 * mi.3.2      ; HT int+ext
mw[3] = mi.2.1 * mi.3.1      ; MT XX
mw[4] = mi.2.2 * mi.3.2      ; HT XX

b1 = rowfix(1)
b2 = rowfix(2)
b3 = rowfix(3)
b4 = rowfix(4)
endrun

;-----
run pgm=hwyload

id = "Final assignment, with deltas, MT & HT

; Input files: network, interim truck trips, rest of the trips
neti    = ..\sp0020.net
mati[1] = ..\e60019.dat
mati[2] = sp00trk.adj
mati[3] = sp00xx.trp

; Output file:
fileo neto = adapt1.lod

; Turn penalties
turnpeni = ..\sp00pen.pen

; Define volume/speed curves for capacity restraint.
function {
  tc[1]= min( t0*20,  t0*(1+0.2* (v/c)^10))
  tc[2]= min( t0*20,  t0*(1+0.05* (v/c)^10))
  tc[3]= tsva/100
}

; Standard BMC assignment parameters.
; increase extracted/computed c by a factor of 11.11 (9% adt factor)
parameters capfac=11.11
combine=sum fractions=1, .1, .1, .1, .1, .1, .1, .1, .1, .1, .1

; Link classes: 1 = freeway, 2 = arterial/coll., 3 = cent. conn.
; Group codes: 1 = HOV, 2 = BWPkwy+895, 3 = No Trucks
phase=linkread
  li.lanes = li.offlane
  tsva     = li.tsva
  if (li.ft=1-2,12) linkclass=1
  if (li.ft=3-10,14) linkclass=2
  if (li.ft=11)     linkclass=3
  if (li.hovlnk=2)  addtogroup=1
  if (li.ft=12)     addtogroup=2
  if (li.notruck=2) addtogroup=3
endphase

; Load X/X separately, on iteration 1 only. Apparently, these trips
; avoid the BW Pkwy and I-895. On subsequent iterations,
; load LOV, HOV, and Trucks separately.
```

```
phase=iloop
  if (iteration=1)
    mw[5] = mi.3.1 + mi.2.3 + mi.2.4 ;PC XX+TK XX
    path=time, peni=1, excludegrp=1-2, vol[3]=mw[5]
  else
    mw[1]=mi.1.1+mi.1.2+mi.1.3+mi.1.4+mi.1.5+mi.1.6+mi.1.15 ;LOV
    mw[2]=mi.1.9+mi.1.10+mi.1.11+mi.1.12+mi.1.13+mi.1.14 ;HOV
    mw[3]=mi.2.1 ;MT w/delta
    mw[4]=mi.2.2 ;HT w/delta
    path=time, peni=1, excludegrp=1, vol[1]=mw[1]
    path=time, peni=1, vol[2]=mw[2]
    path=time, peni=1, excludegrp=3, vol[4]=mw[3], vol[5]=mw[4]
  endif
endphase

; Multiply trucks by a Passenger Car Equivalent factor to reflect
; their effect on capacity.
function V = vol[1] + vol[2] + vol[3] + 1.5*vol[4] + 2.0*vol[5]

endrun
```

References

1. Agnello, P., *Truck Model Recommendation*, internal BMC memo, 23 January 2001
2. *Quick Response Freight Manual*, prepared by Cambridge Systematics for the Travel Model Improvement Program, September 1996
3. *Truck Trip Generation Data*, NCHRP Synthesis 298, prepared by Cambridge Systematics and Jack Faucett Associates for the Transportation Research Board, 2001
4. Allen, W.G., *Adaptable Assignment*, presented at the Sixth TRB Conference on the Application of Transportation Planning Methods, May 1997
5. List, G. and Turnquist, M., *Estimating Truck Travel Patterns in Urban Areas*, Transportation Research Record 1430, 1994
6. Drake, P., *Selected Findings from the Baltimore Trip Attraction Study: Trucks and Other Delivery Vehicles to Retail, Office, and Residential Land Uses*, prepared for the 1988 Annual Meeting of the Transportation Research Board, January 1988

Appendix A

2000 Zonal Employment by Type (Sample)

(Total is the sum of Retail and Non-Retail. Non-Retail is the sum of Office, Industrial, and Other. School is included under Other.)

Zone	Total Empl	School Empl	Retail Empl	Non-Retail Empl	Office Empl	Industrial Empl	Other Empl
1	1388	255	347	1041	273	87	681
2	415	0	50	365	102	51	212
3	1387	225	122	1265	363	101	801
4	4220	80	612	3608	2156	222	1230
5	239	119	2	237	54	33	150
6	1511	166	170	1341	815	19	507
7	1358	0	180	1178	648	32	498
8	7372	63	158	7214	1460	126	5628
9	2077	72	403	1674	446	152	1076
10	2379	628	267	2112	529	227	1356
11	1697	0	465	1232	680	83	469
12	209	72	2	207	47	17	143
13	506	70	167	339	122	12	205
14	2841	124	129	2712	632	66	2014
15	190	0	48	142	84	6	52
16	1203	124	497	706	187	44	475
17	1215	174		1149	321	61	767
18	771	126	23	748	344	54	350
19	344	0	3	341	40	12	289
20	2159	144	16	2143	440	22	1681
21	1198	0	280	918	602	83	233
22	994	107	222	772	361	57	354
23	116	0	27	89	25	39	25
24	261	4	80	181	31	85	65
25	804	0	141	663	116	100	447
26	674	52	69	605	143	57	405
27	370	0	113	257	78	114	65
28	933	132	145	788	158	164	466
29	929	0	140	789	127	186	476
30	1466	444	450	1016	273	62	681
31	944	0	174	770	242	357	171
32	1411	209	268	1143	362	142	639
33	924	189	103	821	233	196	392
34	442	0	56	386	87	9	290
35	219	54	18	201	49	47	105
36	1120	242	100	1020	317	92	611
37	713	92	98	615	215	139	261
38	5498	0	1284	4214	2334	992	888
39	684	0	183	501	145	128	228
40	641	65	98	543	203	87	253
41	3807	0	363	3444	514	1433	1497
42	600	35	42	558	195	48	315

Appendix B 2000 Through Truck Trips

Orig	Dest	MT	HT	Orig	Dest	MT	HT	Orig	Dest	MT	HT
1286	1293	17	1	1293	1315	2	1	1306	1288	0	3
1286	1294	2	1	1293	1324	22	3	1306	1290	2	16
1286	1296	32	81	1293	1325	4	0	1306	1291	2	0
1286	1299	2	11	1293	1326	26	1	1306	1296	2	7
1286	1301	4	66	1294	1286	1	2	1306	1301	0	6
1286	1306	0	4	1294	1301	1	1	1306	1324	0	16
1286	1315	1	34	1294	1315	0	1	1306	1326	1	5
1286	1324	7	104	1294	1324	2	3	1315	1286	1	26
1286	1325	1	10	1294	1326	3	1	1315	1288	0	14
1286	1326	9	56	1296	1286	32	81	1315	1290	6	111
1288	1296	10	44	1296	1288	11	45	1315	1291	5	0
1288	1299	1	6	1296	1289	4	2	1315	1292	0	1
1288	1301	1	36	1296	1290	188	346	1315	1293	2	1
1288	1306	0	3	1296	1291	146	1	1315	1296	5	43
1288	1315	1	18	1296	1292	4	2	1315	1299	0	5
1288	1324	2	58	1296	1299	10	17	1315	1301	1	35
1288	1325	1	5	1296	1301	19	110	1315	1324	2	107
1288	1326	3	31	1296	1306	2	7	1315	1325	0	6
1289	1296	4	1	1296	1315	5	56	1315	1326	1	29
1289	1299	0	1	1296	1324	37	170	1324	1286	6	108
1289	1301	1	1	1296	1325	7	17	1324	1288	3	60
1289	1306	0	1	1296	1326	46	92	1324	1289	1	2
1289	1324	1	3	1299	1286	2	11	1324	1290	41	459
1289	1326	2	2	1299	1288	0	7	1324	1291	31	2
1290	1296	190	342	1299	1289	1	0	1324	1292	1	3
1290	1299	12	46	1299	1290	12	49	1324	1293	21	2
1290	1301	21	280	1299	1291	9	0	1324	1294	1	3
1290	1306	2	19	1299	1292	0	1	1324	1296	37	178
1290	1315	6	143	1299	1293	6	0	1324	1299	2	23
1290	1324	41	437	1299	1294	1	0	1324	1301	5	146
1290	1325	8	42	1299	1296	10	19	1324	1306	0	10
1290	1326	52	235	1299	1306	0	1	1324	1315	1	75
1291	1296	149	1	1299	1324	3	24	1324	1326	10	122
1291	1299	9	1	1299	1325	0	2	1325	1286	2	10
1291	1301	17	1	1299	1326	3	13	1325	1288	0	5
1291	1306	1	0	1301	1286	4	70	1325	1289	0	1
1291	1315	5	1	1301	1288	1	39	1325	1290	8	42
1291	1324	32	2	1301	1289	0	1	1325	1291	6	0
1291	1325	6	0	1301	1290	21	298	1325	1292	1	0
1291	1326	41	2	1301	1291	17	1	1325	1293	4	0
1292	1296	4	1	1301	1292	0	2	1325	1294	0	1
1292	1299	0	1	1301	1293	11	1	1325	1296	7	16
1292	1301	0	1	1301	1294	0	2	1325	1299	0	2
1292	1315	0	1	1301	1296	20	116	1325	1301	1	14
1292	1324	1	2	1301	1306	0	6	1325	1306	0	1
1292	1326	2	2	1301	1316	1	1	1325	1315	1	7
1293	1286	19	2	1301	1324	4	147	1325	1326	1	11
1293	1299	6	0	1301	1325	1	14	1326	1286	8	55
1293	1301	11	1	1301	1326	5	80	1326	1288	3	31
1293	1306	1	0	1306	1286	0	3	1326	1289	1	2

<u>Orig</u>	<u>Dest</u>	<u>MT</u>	<u>HT</u>
1326	1290	51	236
1326	1291	39	1
1326	1292	1	2
1326	1293	26	1
1326	1294	2	1
1326	1296	46	92
1326	1299	3	13
1326	1301	5	75
1326	1306	0	5
1326	1315	2	38
1326	1324	10	117
1326	1325	2	12