# Use of MOVES2010 in Link Level On-Road Vehicle Emissions Modeling Using CONCEPT-MV

Christian E. Lindhjem
ENVIRON International Corporation, 773 San Marin Drive, Suite 2115, Novato, CA 94998

Allison DenBleyker, Michele Jimenez, John Haasbeek, Alison K. Pollack
ENVIRON International Corporation, 773 San Marin Drive, Suite 2115, Novato, CA 94998

Zheng Li
Clark County, 500 S. Grand Central Parkway, Las Vegas, NV 89106

## ABSTRACT

Transportation and air quality modelers in nonattainment areas need to prepare on-road vehicle emissions inventories that are an accurate reflection of the area's activity. On-road vehicle emissions impact air quality both in terms of the daily emission rates as well as the spatial and temporal allocation of those emissions. This work redesigned and applied a computer program, the CONCEPT Motor Vehicle (MV) emissions model, to use EPA MOVES2010 model emission rates in detailed link level on-road vehicle emissions modeling. Presented in this work is a description of that program and emission results using link level activity data for Clark Co. (Las Vegas) Nevada with MOVES2010 emission rates.

## INTRODUCTION

Transportation and air quality modelers in nonattainment areas need to prepare on-road vehicle emissions inventories as inputs to air quality models, and these inventories are often the same or similar (depending upon episode days) to those used in setting and evaluating transportation conformity budgets. More accurate on-road emissions inventories account for temporal activity on individual roadway segments, called 'links' by traffic planners. The activity data for road links usually consists of traffic volumes and capacities, and usually includes additional information on posted or congested vehicle average speeds, vehicle types, and other activity estimates that could affect emissions.

EPA(*1*) has completely revised the on-road vehicle emissions model called MOVES2010, released in December 2009. This model substantially revised the emission rates and process definitions for exhaust and evaporative emissions modes from the previous model, MOBILE6. MOVES2010 also changed the meteorological effects on emissions, vehicle types, and other aspects from the approaches used in MOBILE6. Applying MOVES2010 emission rates to link level activity data required a substantial revision to the emissions analysis approach previously used with the MOBILE6 model because of the new requirements and features of MOVES2010.

Transportation planners use a variety of data sources to estimate on-road vehicle activity within travel demand models (TDM). TDM's contain start and end node coordinates for each link, link distance, link capacity, number of lanes, free flow speeds, method to adjust link speed to account for congestion, and the number of vehicles or "link volume" by time period of day (usually hourly groupings). These models are trip based in the sense that vehicle trips have origins and destinations by traffic analysis zone (TAZ) which are subsets of a metropolitan region but comprise an area around a number of links. TDM's are primarily used to plan for the expected demand on transportation facilities. TDM's are validated with data collected from on-road vehicle counters to calibrate the modeled traffic volumes. The on-road counts for validation include those collected as part of the Federal Highway Administration (FHWA) Highway Performance Monitoring System (HPMS(*2*)). The primary output from TDM models are vehicle volumes, link length, link capacity, and link free flow speed. CONCEPT MV determines the hourly volumes and vehicle miles traveled (VMT) by hour using temporal profiles developed from traffic counter data. CONCEPT MV calculates congested speeds for each road link by hour of day using link volume, hourly capacity, link free flow speed, and speed adjustment algorithms, or an alternative file of vehicle speeds by link-hour can be used if speeds have been determined prior to use in CONCEPT MV.

Air quality models rely on emissions information developed through independent modeling to properly allocate vehicle emissions. ENVIRON developed the CONCEPT MV(*3*) model to estimate vehicle emissions in a highly refined level of detail, both temporally and spatially, for air quality modeling. The CONCEPT MV model produces a high level of spatial resolution by calculating most emissions at the grid cell and hour level. Roadway links across the modeling domain have unique congested speeds due to link specific volume and capacities. CONCEPT MV use trips data by TAZ across the modeling domain to better define the patterned concentrations of trip starts and ends depending on the distribution of residential and commercial zones in the area. Furthermore, CONCEPT MV uses temperature and humidity data specific to grid cells to determine VMT-based emissions on each link in each grid cell and population-based emissions based on vehicle populations in each TAZ and grid cell. CONCEPT MV is a free and publicly available open source software tool that state and local air quality planning agencies use to create emission inventories for air quality modeling to be used in State Implementation Plans (SIPs). Most recently CONCEPT MV has been used in SIP modeling in Clark County (Las Vegas), Nevada; Boise, ID; Denver, CO; and all large urban areas in the Upper Midwest.

This paper describes the technical methods used to incorporate MOVES2010 into link level emissions modeling. To test the demonstrate the model performance, ENVIRON performed test CONCEPT-MOVES2010 runs to generate gridded on-road emissions estimates in Las Vegas area for July 27, 2007 using all of the MOVES2010 emission rates and preliminary link level and off-network activity data.

## BODY

### Implementation of MOVES2010 in Link Level Emissions Modeling

#### MOVES2010 Lookup Table Description and Use

The MOVES2010 model provides lookup tables of emission rates by emission process for use in emissions modeling that use vehicle activity data. Three separate lookup tables called ‘rateperdistance’, ‘ratepervehicle’, and ‘rateperprofile’ collectively contain all the MOVES2010 emission factors for each emission process. Table 1 describes the emission processes incorporated in each lookup table. The rateperdistance table relates directly to on-road vehicle activity while the ratepervehicle and rateperprofile tables contain parked vehicle emissions processes.

**Table 1.** MOVES2010 Emission Factors By Emission Process In Lookup Table Format.

| Process Name | Rateperdistance (g/mile) | Ratepervehicle (g/vehicle/hour) | Rateperprofile (g/vehicle/hour) |
|---|---|---|---|
| Running Exhaust | X | - | - |
| Crankcase Running Exhaust | X | - | - |
| Brakewear | X | - | - |
| Tirewear | X | - | - |
| Evaporative Fuel Vapor Venting | X | - | X |
| Evaporative Permeation | X | X | - |
| Evaporative Fuel Leaks | X | X | - |
| Start Exhaust | - | X | - |
| Crankcase Start Exhaust | - | X | - |
| Extended Idle Exhaust | - | X | - |

| Process Name | Rateperdistance (g/mile) | Ratepervehicle (g/vehicle/hour) | Rateperprofile (g/vehicle/hour) |
|---|---|---|---|
| Crankcase Extended Idle Exhaust | - | X | - |
| Refueling Displacement Vapor Loss | - | - | - |
| Refueling Spillage Loss | - | - | - |

The rateperdistance table provides emission rates in units of grams per mile as a function of vehicle speed at 2.5 mph and 5 mph increments from 5 to 75 mph. The speed bins and associated emission factors can be used to interpolate emission rates for any speed within that range by each of four road types (rural and urban, restricted and unrestricted access). The rateperdistance emissions rates are affected by temperature and humidity in a complex relationship incorporating both the direct impact on engine exhaust emission rates and the indirect impact on emissions from increased air conditioning loads on those engines. Therefore, the MOVES2010 model must be run multiple times to create lookup tables by speed for the entire range of temperature and humidity conditions experienced in any grid cell during an emission modeling episode.

The ratepervehicle and rateperprofile tables provide emission rates in units of gram per vehicle for each hour of day. The ratepervehicle table includes all of the parked vehicle emissions processes with the exception of an 'evaporative fuel vapor venting' process. The emission rates are provided for each hour of day and include unique relative activity profiles so the emission rates are different for each hour of day under the same meteorological conditions. Most of the ratepervehicle processes' emission rates depend upon temperature and hour of the day. However, the NOx emission rates from the extended idle exhaust and extended idle crankcase exhaust depend on temperature and humidity. The emission rates for each of the 24 hours of the day need to be determined over the temperature range experienced in the episode modeled. Humidity affects the NOx exhaust emission rates using the algorithm as described in the MOVES2010 technical documentation. CONCEPT MV adjusts extended idle NOX emission rates based on grid cell absolute humidity according to MOVES methodology(*4*) rather than running MOVES at the range of humidity values.

The rateperprocess table emission rates depend upon the daily temperature profile accounting for both the diurnal temperature history and vehicle activity by time of day. The parked vapor venting was then estimated by vehicle by hour using the regional average temperature profile.

Meteorological Preprocessing

The gridded meteorological data for the region was preprocessed to determine all conditions necessary for input to MOVES for preparing emission factors required by CONCEPT MV:

- Minimum and maximum temperature in any grid cell and hour
- Minimum and maximum relative humidity in any grid cell and hour
- Diurnal temperature profile per episode day

The data was then used to create bins for which to run MOVES2010, producing lookup table emission rates at each temperature and humidity bin. For this work a bin increment value of 5 was chosen for both temperature and relative humidity, or the increment may be changed by the user. Preprocessing gridded meteorological data for a two-day July episode in Clark County, Nevada resulted in a lookup range of temperatures ranging from 55°F-105°F and a range of relative humidity from 15%-70%. An increment of 5 with these two ranges results in 11 temperature and 12 relative humidity values, which multiply to 132 combinations for the rateperdistance tables, and 11 conditions for the ratepervehicle tables. In addition, the regional average temperature profile was created for each episode day to prepare MOVES2010 rateperprofile emission rate tables.

Link Level Activity

Clark County provided the TDM vehicle volumes for links by hour of day (often the data is available for groups of hours that need to be allocated to each hour) along with the link description by road type and link capacity. Each link's ratio of volume to capacity were used to estimate the average speed for that hour. The link free flow speeds were adjusted for congestion using the Bureau of Public Roads (BPR) algorithms[2] to estimate average speed, though CONCEPT MV allows for other algorithms or an external speed file.

During congested periods the traffic volumes may exceed the capacity for a link, and queues may form. Hence speeds will be lower than would be estimated at capacity. CONCEPT MV determines the queue length as a function of the number of vehicles exceeding the capacity and assumes the queued speed equals the minimum bin speed of 2.5 mph. The traffic along the link length before the queue is estimated to proceed at the congested speed calculated assuming the link volume equals capacity. Finally CONCEPT MV uses a time weighted average to determine the link speed for that hour.

Other Supporting Data: Population, Traffic Counts by Vehicle Type, and Trips by TAZ

Vehicle population by source (vehicle) type is a key input to MOVES2010. Vehicle populations can be estimated from the vehicle registration data or estimated from the area-wide vehicle miles traveled (VMT) using approximate average daily travel to estimate the vehicle population by vehicle type. In this work, vehicle population was determined from a mix of vehicle registration for light-duty vehicle types, and VMT estimates for some of the larger truck types.

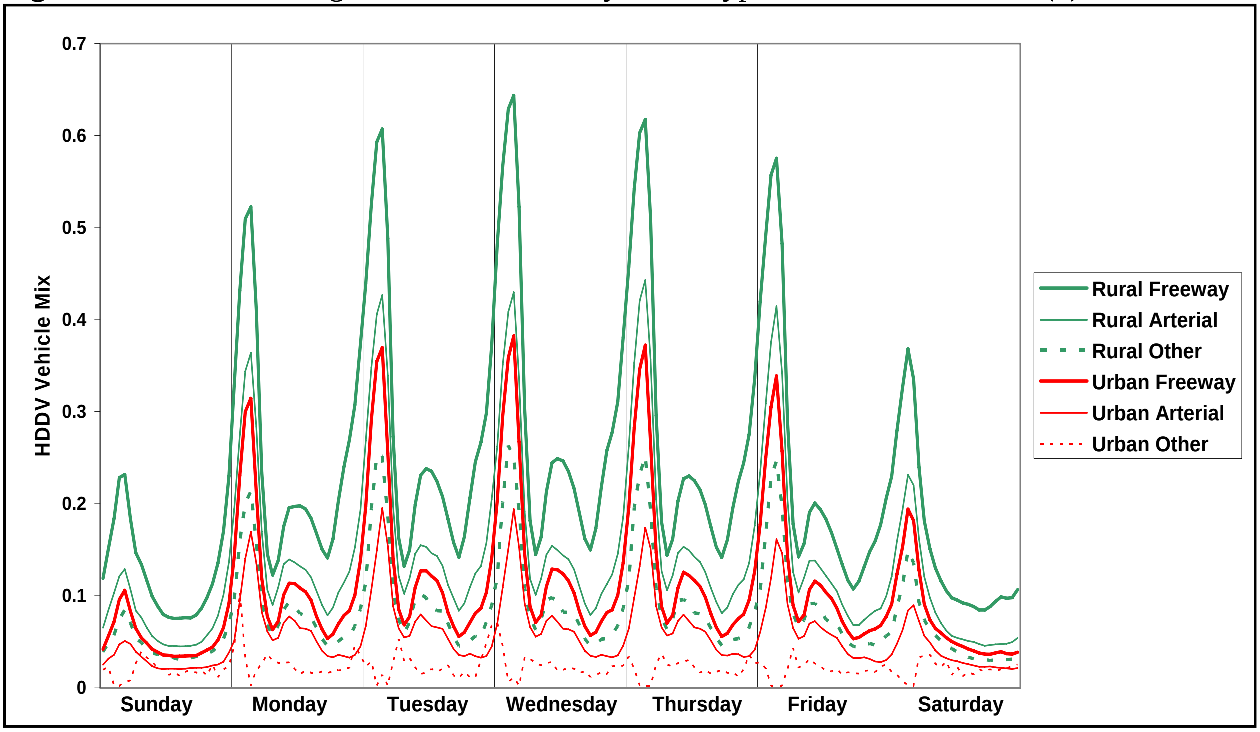
In addition to TDM traffic volumes (and VMT) by time period, another type of traffic data is utilized for detailed emissions modeling in CONCEPT MV. Special automatic traffic recorder (ATR) devices at some monitoring sites make continuous counts of vehicles classified by type and can be used to estimate the relative activity by vehicle type by time of day and road type. Table 2 describes the vehicle types available from vehicle classification data (FHWA) and how those vehicles compare to MOVES2010 source types.

**Table 2.** Vehicle Type Descriptions.

| **FHWA Vehicle Class** | **MOVES Source Type** | **Source Type Name** |
|---|---|---|
| 2 | 21 | Passenger Car |
| 3 | 31 | Passenger Truck |
| | 32 | Light Commercial Truck |
| 5, 6, 7 | 51 | Refuse Truck |
| | 52 | Single Unit Short-haul Truck |
| | 53 | Single Unit Long-haul Truck |
| | 54 | Motor Home |
| 4 | 43 | School Bus |
| | 42 | Transit Bus |
| | 41 | Intercity Bus |
| 8 – 13 | 61 | Combination Short-haul Truck |
| | 62 | Combination Long-haul Truck |
| 1 | 11 | Motorcycle |

Methods developed by ENVIRON(*5*) were used with vehicle classification counter data to estimate vehicle type fractions (called vehicle mix) that vary by road type and hour of day for FHWA vehicle classes. Figure 1 shows an example of a national average variation in heavy-duty diesel vehicle (HDDV) fraction, with rural road types and overnight periods populated by more HDDV than urban road types and other times during the day. Because the FHWA vehicle classes do not match MOVES2010 source types, the relative fraction of the default vehicle population within MOVES2010 source types was used to distribute the FHWA vehicle class fractions in to MOVES2010 source type fractions. ATR data and an FHWA-to-MOVES2010 cross reference were used together to develop the temporal distributions of VMT by MOVES2010 source types by road type for use in CONCEPT MV.

**Figure 1.** National Average HDDV Fraction By Road Type And Hour Of Week. *(5)*




Lastly, the trip starts and ends data by TAZ and time period was used to allocate vehicle population for start and parked vehicle emission processes. The relative number of trip starts and ends for each TAZ compared to the total number in each hour was used to allocate the vehicle population to the TAZ for start and parked emissions. Figures 2 shows an example of the trip start activity by TAZ used to allocate start exhaust emissions, and Figure 3 show an example of the trip end activity to allocate other parked emissions.

**Figure 2.** Clark County, Nevada Trip Start Concentrations By TAZ For Mid-Day 9 AM to 2 PM.

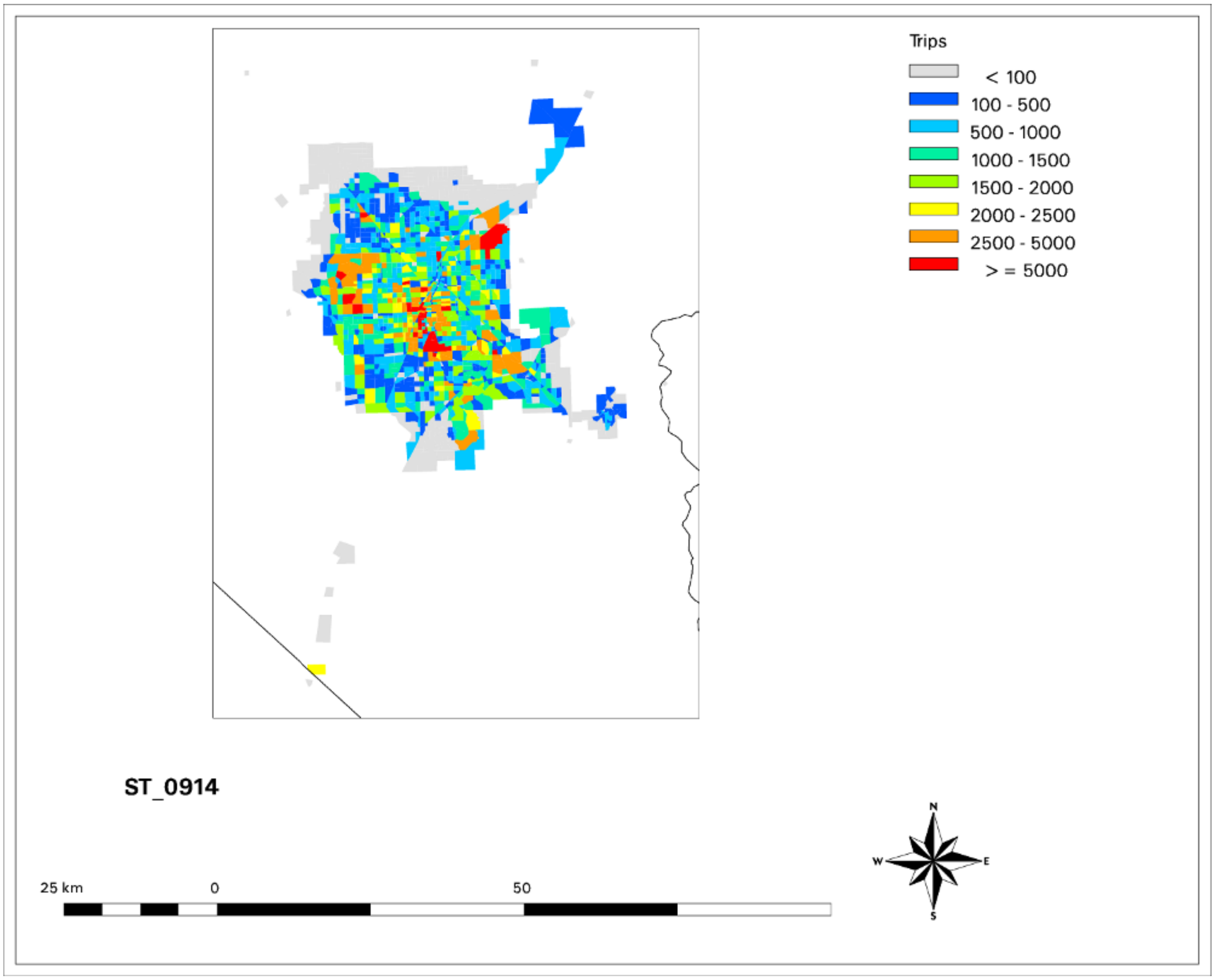
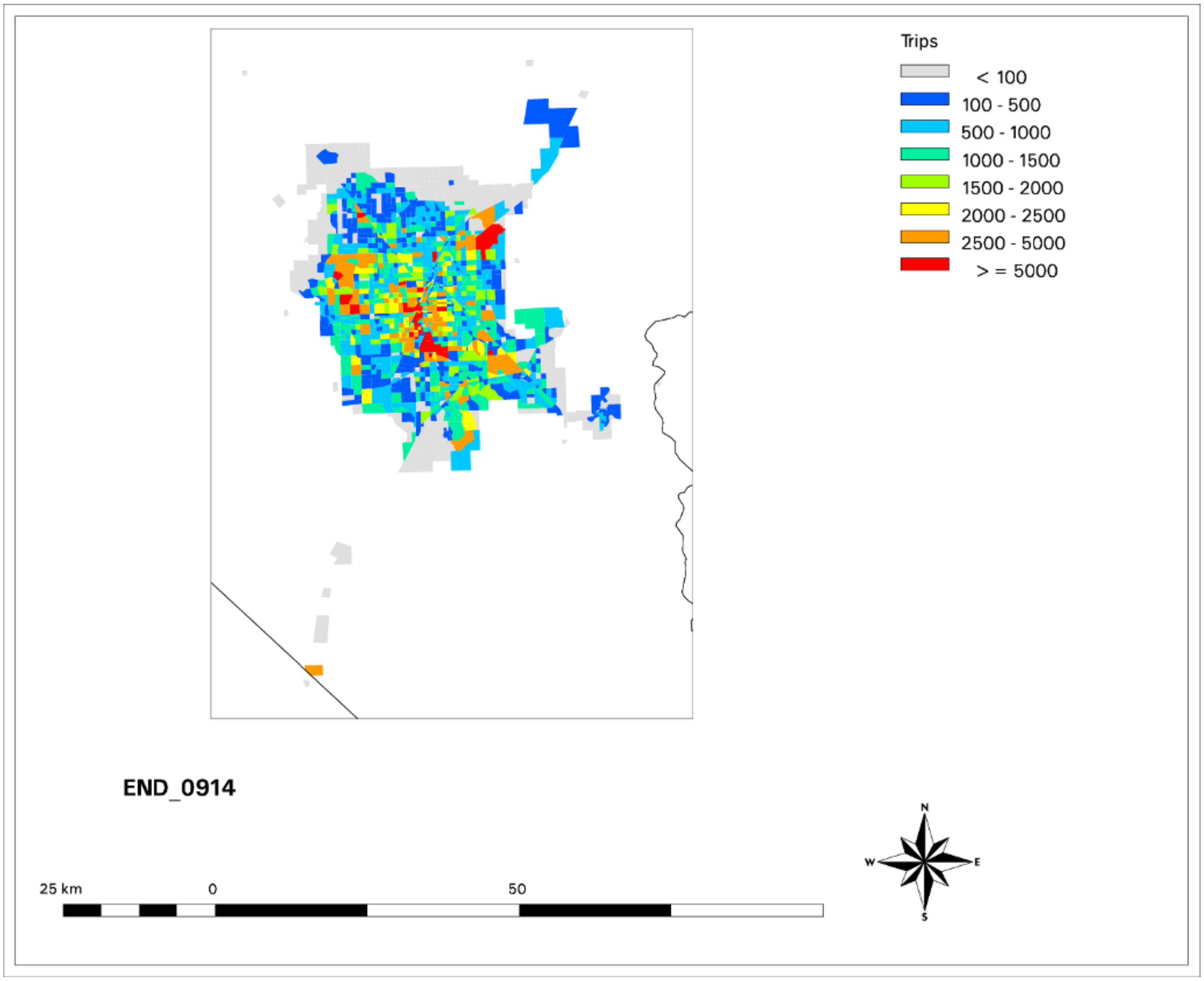


**Figure 3.** Clark County, Nevada Trip End Concentrations By TAZ For Mid-Day 9 AM to 2 PM.




Spatial Allocation Surrogates

One of the main advantages of using link level activity data is the ability to precisely estimate emissions spatially and temporally. The benefit is more accurate emission data in air quality modeling resulting in a better understanding of emission sources responsible for local and regional air quality conditions.

The link vehicle traffic volumes by hour of day coupled with the spatial description of link nodes precisely defines the running emissions in space and time. The traffic volumes and link capacity determine the vehicle average speed and therefore the emission rates by vehicle type. The distribution of vehicle types by road type and hour of day provide a better estimate of the overall fleet emissions rates to apply to the traffic volume for each hour on each link.

The CONCEPT MV model uses an advanced approach to spatially allocate start and parked emissions processes. Exhaust emissions from starting a vehicle engine, and the evaporative emissions (vapor venting, leaks, and permeation) that result from vehicles while vehicles are parked off the link network may be associated with vehicle trips. Transportation modelers develop estimates of trip origins and destinations by TAZ based on travel surveys for use in their TDM. The relative trips across the urban area can be used to provide an improved spatial estimate of where these parked emissions are occurring, rather than placing the emissions on the link network. Trip starts are particularly important because emission rates during starts are significantly higher than those when the vehicle is running. In EPA's MOVES2010 model, the start emissions are separate from the running emissions. Extended idle exhaust from heavy diesel trucks is another emission process that does not belong on the links. For Las

Vegas, an improved spatial surrogate was developed based on the locations of major truck rest stops in Clark County.

The spatial distribution of vehicle populations across the region changes by time of day. On a typical weekday morning the majority of passenger cars and trucks have trips originating from residential zones (trip starts) and ending in commercial zones (trip ends). In the afternoon period, trip direction reverses. CONCEPT MV allocates vehicle populations to grid cells by time period using the relative proportion of trips by TAZ. The relative trip starts are used the allocate population to grid cells before calculating start emissions. Likewise, the relative distribution of trip ends by TAZ is used to allocate population that CONCEPT MV then uses to compute parked evaporative emissions for permeation and fuel leaks. The emission rates for the 'Evaporative Fuel Leaks' and 'Evaporative Permeation' emission processes are calculated from TAZ grid cell temperatures. A user can specify alternative spatial allocations schemes for parked vehicle emissions in CONCEPT MV.

Extended idle is an emission process exclusive to the 'combination long-haul truck' source type, and is meant to model idling activity to provide environmental comfort to drivers during layovers. In the Las Vegas modeling, CONCEPT MV allocates extended idle emissions to the relative number of parking spaces at major area truck stops.

**Results**

ENVIRON prepared regional emission inventories for Clark County using all of the MOVES2010 emission rates and processes and preliminary link level and off-network activity data in CONCEPT MV. To test and demonstrate the model performance, CONCEPT MV was run for one day using approximate vehicle link level traffic volume and area population estimates. The emission results presented in this work are preliminary and depend on many input factors of which vehicle population by vehicle type have more uncertainty than others. The vehicle population is an important input estimate for emission processes other than running exhaust. The results were generated for a Friday during the summer period in 2007 using detailed link level vehicle activity data from TDM output as the activity input and MOVES2010 emissions rates for the meteorological conditions for this episode.

Figures 4 and 5 show the total organic gas (TOG) and nitrogen oxide (NO; the other component of NOx is NO2 and is a much smaller fraction of NOx and is provided as a separate estimate in MOVES2010 lookup tables) emissions by emission process from passenger cars in this regional area. The start exhaust emissions are a particularly important emission process for both TOG and NO. The evaporative emissions (collectively vapor venting, permeation, and leaks) are the most important emission processes for TOG emissions.

**Figure 4.** Total Organic Gas (TOG) Emissions From Passenger Cars By Emission Process By Hour Of Day For A Weekday In 2007.

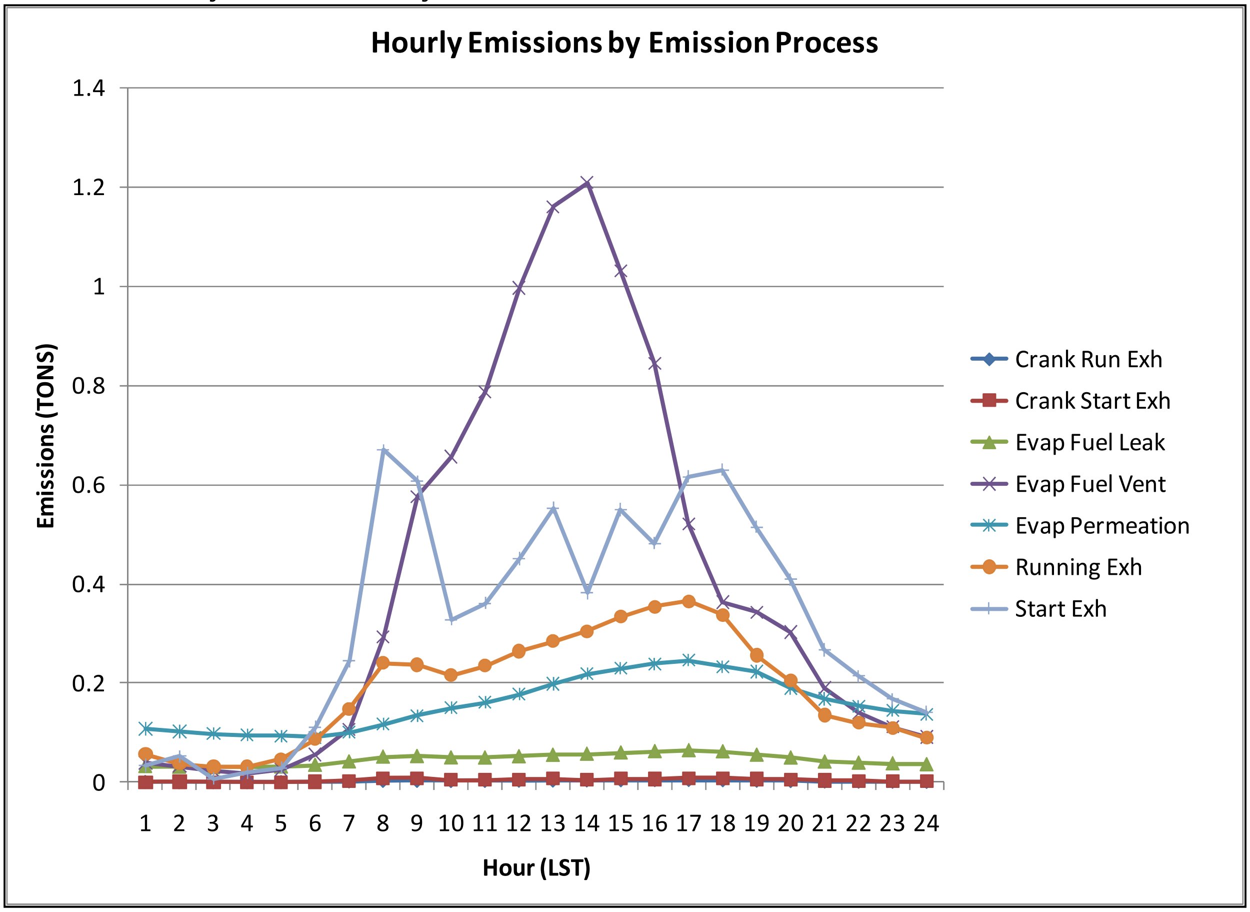
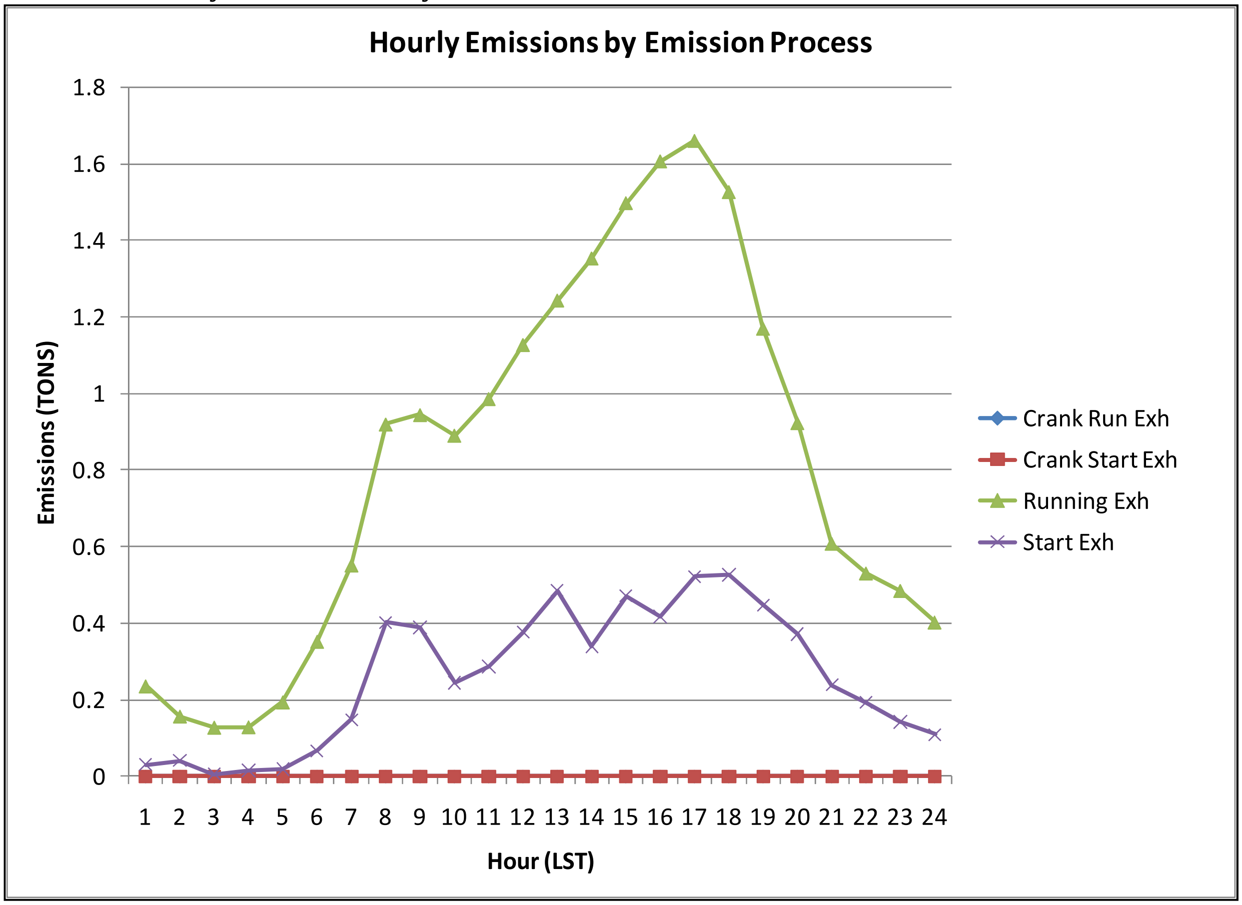


**Figure 5.** Nitrogen Oxide (NO) Emissions From Passenger Cars By Emission Process By Hour Of Day For A Weekday In 2007.




The emissions by source type demonstrate the importance of the vehicle type estimates by road type and time of day. Figure 6 shows that the TOG emissions are due to light-duty vehicles, which is an expected result. However, motorcycle TOG emissions are a small but noticeable, approximately 5%, fraction of the total TOG emissions despite comprising an extremely low fraction of the VMT. Figure 7 shows the relative importance of heavy and light-duty vehicle activity on NO emissions, where heavy-duty vehicles are responsible for about half of the NO emissions despite adding up to less than 10% of the VMT. The heavy-duty activity is skewed to the early morning hours, so morning NO emissions are higher than would be expected from the overall average activity.

**Figure 6**. Total Organic Gas (TOG) Emissions By Source Type By Hour Of Day For A Weekday In 2007.

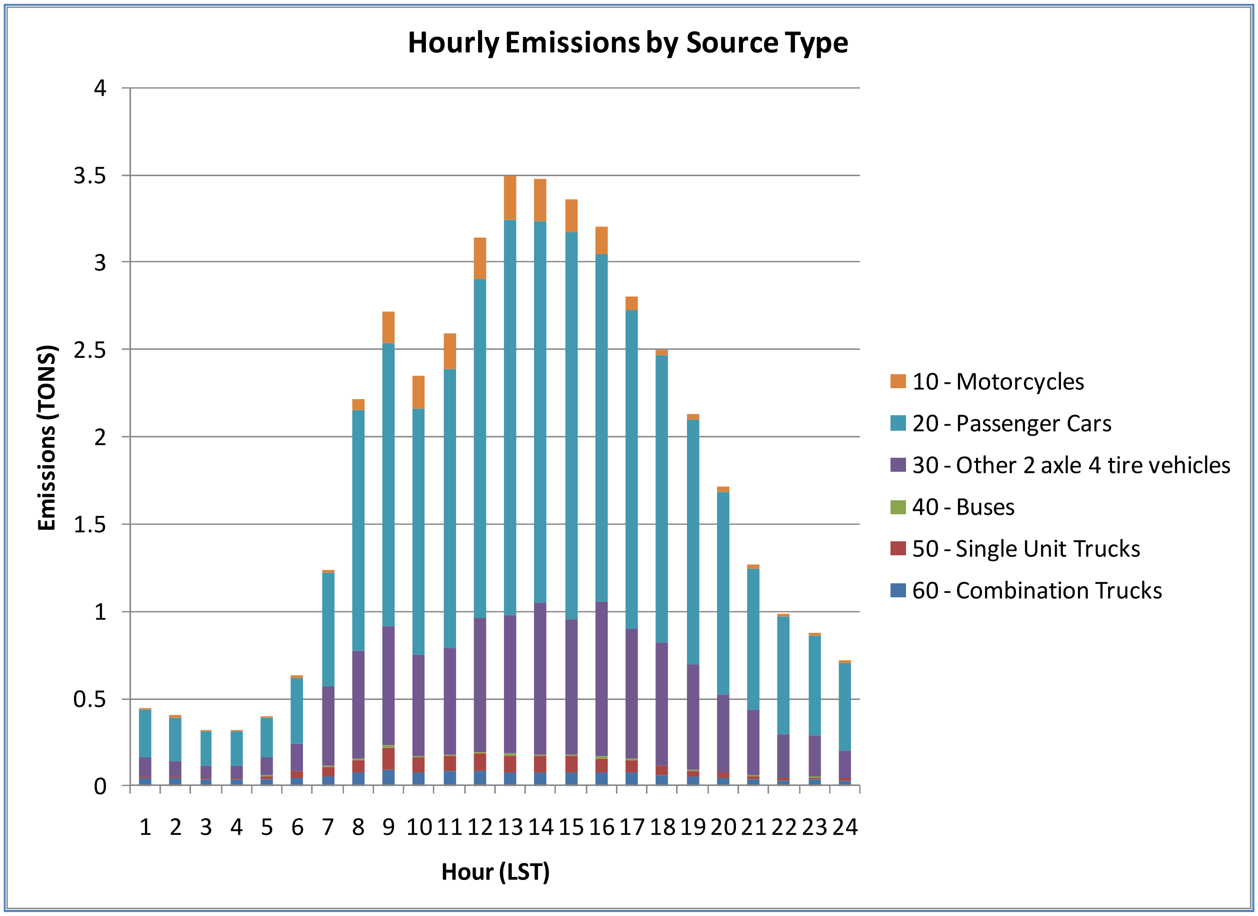
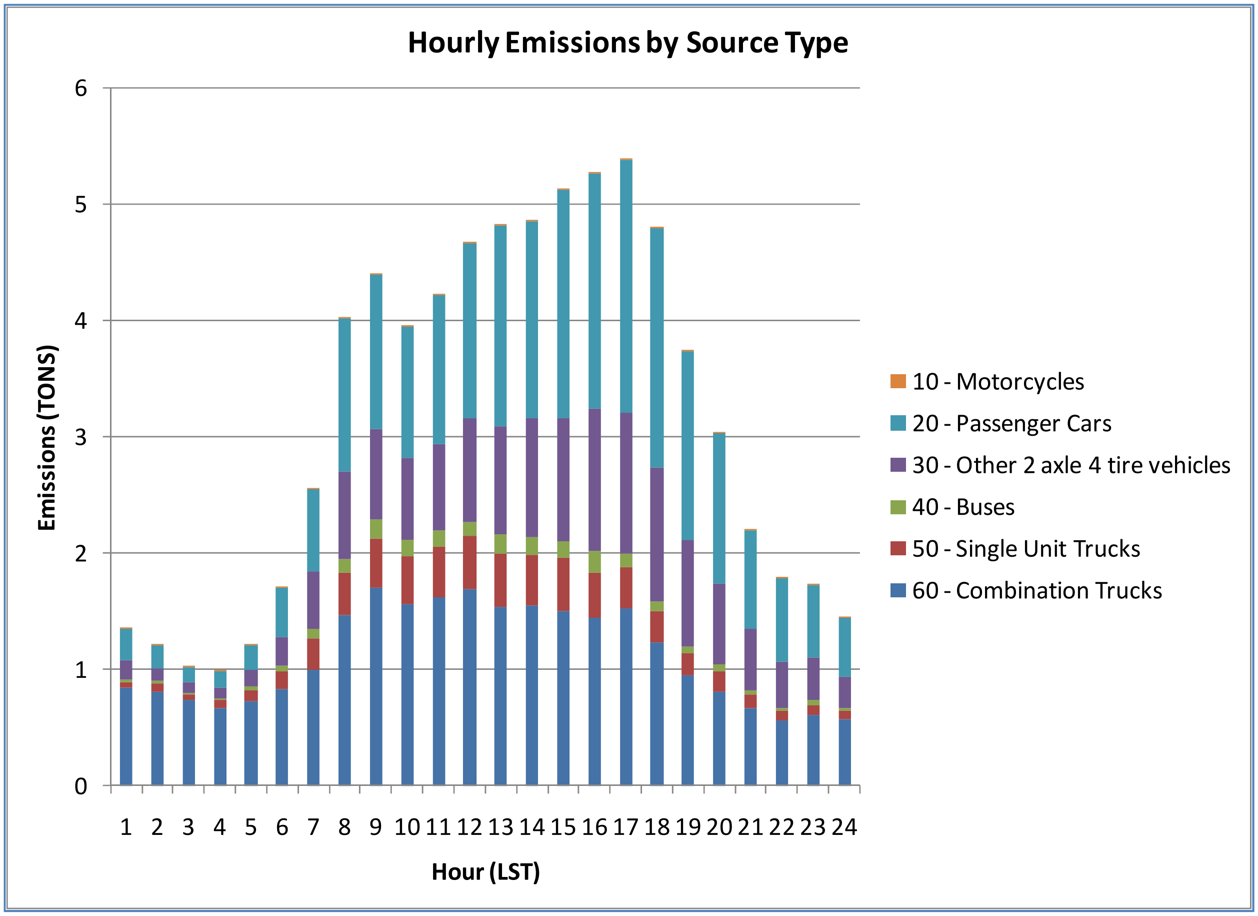


**Figure 7**. Nitrogen Oxide (NO) Emissions By Source Type By Hour Of Day For A Weekday In 2007.




Another important benefit of using link level and TAZ trips data is to provide detailed spatial allocation of emissions. Figures 8 and 9 show the daily TOG and NO emissions by grid cell for this region. While the running emissions are centered on the freeways where the VMT is the highest, the allocation of start exhaust and evaporative emissions were distributed to the areas where trips begin and end. Therefore the emissions were provided with better detail for air quality models than would have occurred using relative VMT. The CONCEPT MV model provides such detailed spatially allocated emissions for each hour of the day though Figures 8 and 9 show only the daily totals. The spatial allocation was prepared for 4 km by 4 km grid cells, but a finer resolution is possible given that the size of the links and TAZs are often smaller than that scale.

**Figure 8.** Total Organic Gas (TOG) Emissions (moles/hr) By Grid Cell For A Weekday In 2007.

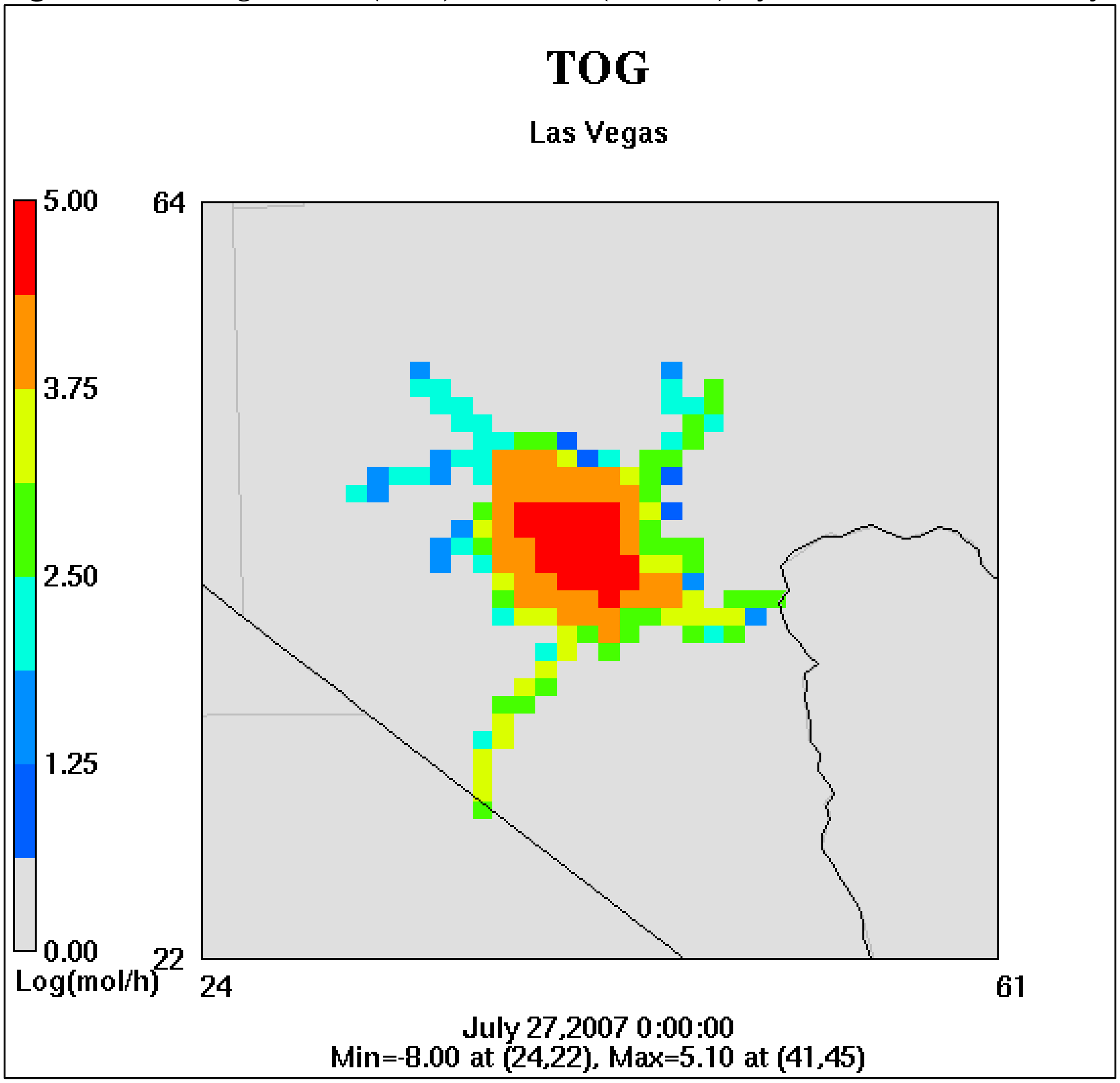
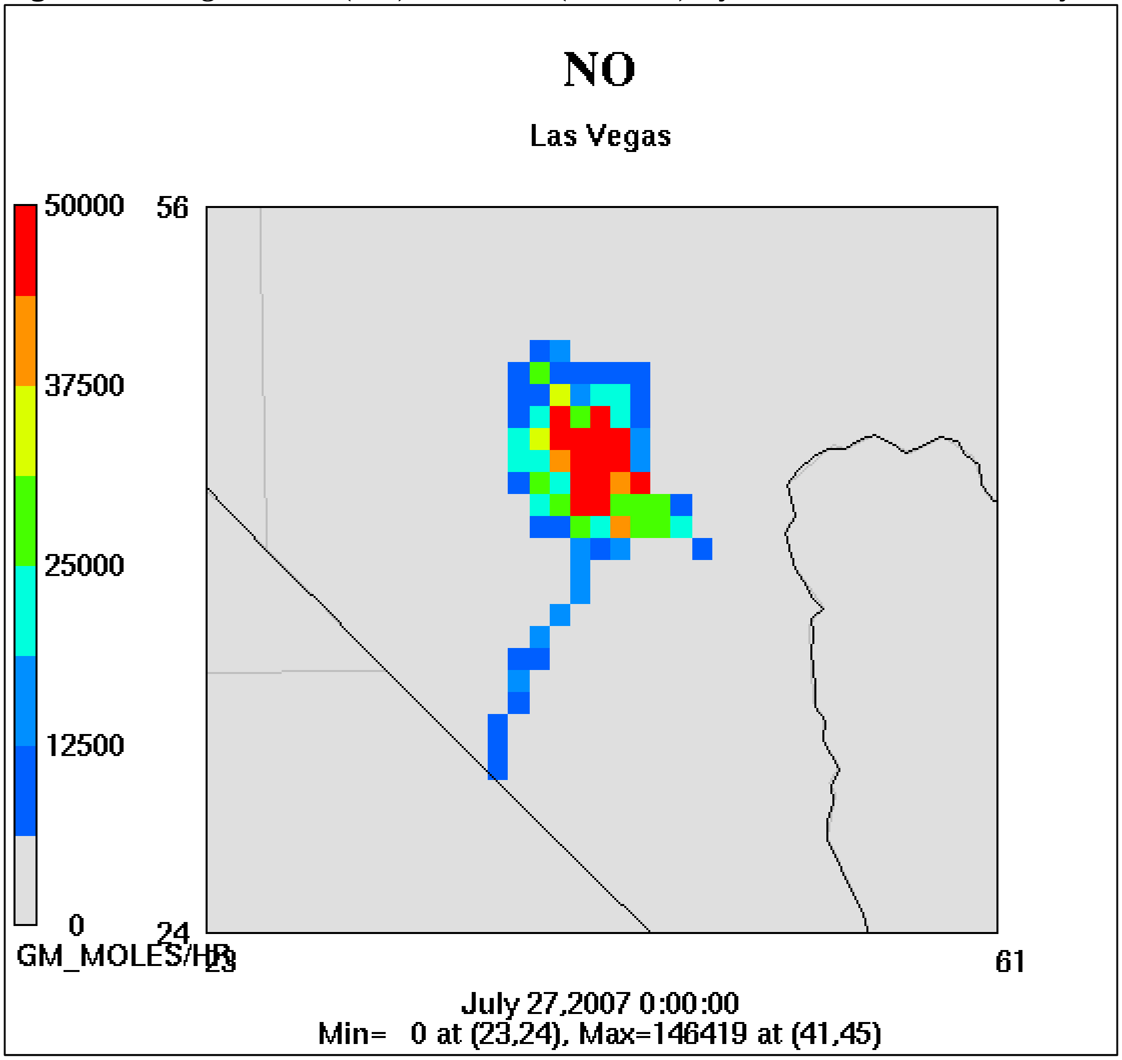


**Figure 9.** Nitrogen Oxide (NO) Emissions (moles/hr) By Grid Cell For A Weekday In 2007.




## CONCLUSIONS

In this work, ENVIRON has designed and implemented a method with the public CONCEPT MV model to use MOVES2010 with link level activity data to prepare detailed spatial and temporal emission estimates of on-road vehicles for a metropolitan area. The emission estimates produced by CONCEPT MV are formatted for use in air quality models that are used for State Implementation Plan (SIP) development.

## REFERENCES


1. U.S. Environmental Protection Agency. *MOVES Motor Vehicle Emission Simulator*, Available online at http://www.epa.gov/otaq/models/moves/index.htm
2. Federal Highways Administration. *Highway Performance Monitoring System (HPMS)*, Available online May, 2010 at: http://www.fhwa.dot.gov/policy/ohpi/hpms/index.cfm.
3. Pollack, A.K.; Haasbeek, J.; Janssen, M., "Development of Link-Level Mobile Source Emission Inventory", Presented at the 14th International Emission Inventory Conference of the U.S. Environmental Protection Agency, Las Vegas, NV, May 2010; Available online at: http://www.epa.gov/ttn/chief/conference/ei14/index.html

4. U.S. Environmental Protection Agency. *Draft MOVES2009 Highway Vehicle Temperature. Humidity, Air Conditioning, and Inspection and Maintenance Adjustments*, EPA-420-P-09-003, August 2009.
5. ENVIRON International Corporation. *Development Work for Improved Heavy-Duty Vehicle Modeling Capability Data Mining – FHWA Datasets*. EPA/600/R-07/096, July, 2007. Available at: http://www.epa.gov/nrmrl/pubs/600R07096/600r07096.htm

**ACKNOWLEDGEMENTS**

ENVIRON wishes to acknowledge the funding and review of this work by Zheng Li of Clark County, Nevada, and the continuing in-kind support of the EPA Office of Transportation Air Quality in using and understanding the MOVES2010 on-road vehicle emissions model.

**KEY WORDS**

Vehicle
Emissions
On-Road