Cargo Handling Emissions Inventory Methodology

The Cargo Handling Emissions Inventory (CHEI) model is available online through the ARB website along with this file. The following is divided into three major sections of methodology: 1. Vehicle Turnover and Purchasing (taken from the 2011 CHE Amendments ISOR technical appendix), 2. 2005 Rule and 2011 Amendments Implementation, and 3. Input Table Details. Also, see the ‘CHEI Inputs’ file for coding and information regarding some of the input tables discussed in section 3.

1. **Turnover and Purchasing**

### Turnover

Turnover is a function that describes the relationship between equipment age and the proportion of equipment that has been removed from the fleet. These vehicles may leave a fleet because of scrappage or because they are being sold to another fleet. The function is expressed in terms of a fraction of vehicles by age that remains in the population. The average lifetime varies by the type of equipment and the fleet. For this updated inventory staff relied on the turnover rate curves as defined by EPA (EPA, 2005). EPA provides equations for which the user defines the useful life and maximum age of the equipment. Useful life is defined as the age where 50% of the vehicles have been turned over and the maximum life is the age at which all the vehicles have left the fleet. The application of these turnover functions was tailored to align with our understanding of the fleet useful life information included in the reporting data.

In order to reflect fleet turnover characteristics staff developed useful life and maximum life inputs based on groups of equipment fleets with similar average ages. For example, all yard tractor fleets with an average age around 5 years follow the same turnover trends whereas yard tractor fleets with an average around 10 years follow their own turnover trend. This way, smaller fleets which are difficult to model can follow the trends of similarly-aged larger ones.

Turnover rates follow a traditional s-curve, but the shape of the curve is defined by the useful life and maximum life. Based on the age distributions developed from the grouped data in the table above staff identified the useful life as 1.5 times the average age of the equipment. The maximum age was defined as the 98th percentile of the age distribution. The following graphs are examples of the s-curves for RTG cranes with an average age of 6 and forklifts with an average age of 21. As you can see, for these example fleets RTG cranes are generally turned over by age 10. In the other example fleet, forklifts are maintained until almost 35 years old.

Figure I‑1: Example Turnover Rates for Cranes and Forklifts

**Turnover Curve Development**

The general shape of the turnover function, or s-curve, is very similar to the function used for the original inventory. However, for this update staff developed inputs specific to individual fleet and equipment type characteristics. These turnover rates were developed in three steps: (1) Group similar fleets into the same category; (2) Develop a Business As Usual (BAU) age distribution; (3) Stretch or compress the curve so turnover models the BAU distribution. The result is that locations with a similar average age will follow the turnover rates.

*(1) Group similar fleets into the same category*

Since some location and equipment types have such a small population fleets with similar characteristics were grouped together. Different equipment types, however, were never modeled using the same turnover rates since the data shows that the different CHE equipment types are too unique to have the same turnover assumptions. Locations that were grouped together were based on average vehicle age into a (L)ow, (M)edium, (H)igh, or (O)ver-high category. For example, all the equipment given a ‘High’ average age designation are used to develop the same BAU age distribution, which will be discussed in more detail later.

*(2) Develop a Business As Usual (BAU) age distribution*

Once the categories have been established, many different sources of population data are compiled to develop an age distribution that represents business as usual in the absence of the regulation. To develop this BAU age distribution staff relied on the regulatory reporting database (ARB, 2005), the annual inventories for the Port of Los Angeles/Port of Long Beach (Starcrest, 2010), the 2005 Port of Oakland inventory (Starcrest, 2008b), the 2005 Railyard Health Risk Assessment inventories (ARB, 2008), and ARB’s 2004 CHE equipment survey. The BAU age distributions were developed from a polynomial fit of the data. These curves are then used for turnover and purchasing and are unique to each *category* of location-equipment type.

*(3) Stretch or compress the curve so turnover models the BAU distribution*

The useful life of the turnover function was determined to be at 1.5 times the average age of the BAU distribution because this is where the distributions had a significant drop off in population. It was also observed that the model preserved BAU well at this useful life. The max life was placed at the 98th percentile of the population data. Any equipment that was reported older than this had a very large standard deviation from what was normal; increasing the max age to include these outliers would result in a population much older than anticipated.

## Purchasing

The other component of equipment turnover is purchasing. Purchasing is very specific to each fleet. Some fleets maintain vehicles that are very young and thus purchase young vehicles. Other fleets maintain older equipment and thus purchase older vehicles. Since the updated inventory developed for these amendments is fleet group and equipment specific purchasing behavior was necessary at this level of detail.

In order to establish purchasing habits for each fleet group an historically average baseline age distribution was developed. This distribution, hereby referred to as the ‘business as usual age distribution’ was estimated from 2001-2007 historical equipment inventory data (see Turnover Curve Development above). This age distribution represents the age distribution of the fleet in the absence of the rule and recession. This distribution was used as a target age distribution in projecting fleet turnover in the absence of the recession and regulation. The distribution of vehicle purchases was determined by the business as usual age distribution for the baseline inventory. New vehicle purchases under the rule inventory were dictated by the rule requirements. The example for yard trucks below helps to illustrate the concept. The blue line is the 2006 age distribution. After attrition is applied the resulting population (the dark green line with boxes) is a year older and smaller as a result of vehicles leaving the fleet (turnover). To determine the age of vehicles purchased the business as usual (BAU) age distribution is used to distribute new vehicle purchases among the ages where the attrited 2007 population is below the business as usual population. These purchases are added to the 2007 attrited population resulting in the 2007 grown population (light green line with triangles). In reality this adjustment takes into account both purchasing and necessary modifications to turnover rates where the estimated turnover assumptions don’t exactly match fleet behavior. Over time the base year age distribution will move towards resembling the business as usual age distribution.

Figure I‑2: Purchasing Example for 2006 to 2007 population change



**Purchasing Distribution**

After turnover has been applied to a given population purchasing is distributed among model years to eventually reestablish the BAU age distribution. These purchases enter the fleet as a result of turnover and growth and are accomplished in two steps: (1) Calculating the number of total vehicles that need to be purchased; and (2) Distributing the purchases so the BAU distribution is eventually reestablished.

*(1) Calculating the number of total vehicles that need to be purchased*

The total number of vehicles that need to be purchased is a function of the number retired and the expected growth from one year to the next. The growth of a population is calculated by multiplying the count of equipment before retirement by a growth factor (see ‘6. Growth & Recovery’ in the 2011 CHE Amendments ISOR Technical Appendix). The total number of vehicles to be purchased includes those that have been turned over and those needed to meet the expected growth.

*(2) Distributing the results so the BAU distribution is reestablished into the future*

The total number of vehicles purchased is distributed among model years so that each age bin gets relatively closer to the BAU distribution. If an age bin is already above the BAU distribution there is no purchasing for that bin. The percentage of vehicles given to each bin is chosen so that each gets proportionally closer to BAU. For example, if 3 vehicles are to be distributed between age 3 and age 5 which have populations of 8 and 10 respectively, and BAU has these populations both at 12 vehicles, then the age 3 bin gets 2 vehicles and age 10 bin gets 1 vehicle.

For details on the implementation of the turnover and purchasing methods above, see the CHEI model coding. The code itself is commented and grouped into sections for a clear understanding of the methodology.

1. **2005 Rule and 2011 Amendments Implementation**

There are two categories of equipment under the 2005 CHE regulation: yard trucks and non-yard trucks. They follow different compliance schedules and have different options for compliance. The 2005 Final Regulation Order containing compliance schedules and options is available online

<http://www.arb.ca.gov/regact/cargo2005/revfro.pdf>

The CHEI model has two separate procedures for the two categories of yard trucks (PopulationForecastRuleYT) and non-yard trucks (PopulationForecastRuleNonYT). In addition, the non-yard truck procedure contains code that implements the 2011 amendments. The procedure is run once with this code turned off for the 2005 rule and then turned on for the 2011 amendments. The following sections describe the two regulation categories and the implementation of the amendments for non-yard truck equipment.

1. **Yard Truck Regulation (2005)**

The yard truck regulation is implemented in two steps: (1) Load the percentage of equipment that should comply in a given year; and (2) Calculate the number of vehicles that need to retire that year.

1. *Load the percentage of equipment that should comply in a given year*

On page 11 of the Final Regulation Order there is the compliance schedule for different categories of yard trucks. This table exists in the model as ‘RegYTComp’ (see 3. Input Table Details). Note that the table for small fleets on page 10 and the table for on-road engines with VDECS applied are not used in the model (a simplification that affects the inventory by less than 0.1%). To find the percent of equipment that should be in compliance for any year the percentages in the table are multiplied against the base year population (the population in 2006). The percentage represents the percent that should have retired that year (the only compliance option for yard trucks is to retire the vehicle and replace it with a new one if necessary). In addition to the retirement from the regulation some vehicles have already been retired by natural turnover so this number must be adjusted (see next).

1. *Calculate the number of vehicles that need to retire that year*

The 2005 rule scenario preserves baseline attrition/turnover each year. The baseline attrition method is applied before the population is affected by the regulation. But note that purchasing for the rule scenario is adjusted so that equipment that is purchased is brand new, which is a requirement of the regulation. The vehicles retired by natural attrition are counted towards compliance because it is a percentage of the base year population that are required to retire. For example, if there are 10 vehicles in the base year, natural turnover retires 2 of them, and the regulation requires that 50% need to be retired, then the methods will results in only 3 additional vehicles retiring so that 5 /10 = 50% of the fleet retired. The 2 vehicles retired by attrition count towards the 5 that needed to retire.

1. **Non-Yard Truck Regulation (2005)**

The non-yard truck regulation is implemented in three steps: (1) Load the percentage of equipment that should comply in a given year; (2) Calculate the number of vehicles that need to retire that year; and (3) Calculate the percentage of vehicles complying by each compliance option. In addition to these compliance methodological steps there are (4) NoVDECS extensions; and (5) Future compliance for expired VDECS and experimental RTG crane VDECS (beyond 2014).

1. *Load the percentage of equipment that should comply in a given year*

On page 15 of the Final Regulation Order there is the compliance schedule for all non-yard truck equipment. Unlike the yard truck regulation, all equipment types are treated the same. This table is implemented into the model in table ‘RegNonYTComp’ (note that the compliance for fleets of 3 or less is not included for simplicity, this affects a very small portion of the population). These percentages are multiplied against the base year population (the population in 2006) for a given calendar year and the result is the number of vehicles that need to comply that year (non-yard truck equipment operators have several options for meeting compliance – see Final Regulation Order and (3) below).

1. *Calculate the number of vehicles that need to retire that year*

Methodology is identical to yard trucks (see (2) under Yard Truck Regulation)

1. *Calculate the percentage of vehicles complying by each compliance option*

Operators have several options for compliance (see regulation order). The percentages of expected compliance behavior are available in table ‘RegNonYTAssumptions’ (see Input Table Details below). Staff estimated how fleets would comply by using the compliance-to-date and expected purchasing habits (tier 4 engines are not as available in the early years of the regulation). Compliance-to-date was part of the requirement of the original regulation. Operators must report compliance measures taken; this information is implemented into the update model.

1. *NoVDECS Extensions*

The 2005 rule allows extensions for operators that choose to retrofit equipment but do not have a verified diesel emission control strategy (VDECS) device available.Their compliance schedule is delayed 2 years (see table ‘RegNonYTComp2YrExt’ in 3. Input Table Details). Along with the equipment that has been reported as ‘no VDECS available’, ARB conducted a study in 2010 to determine potential safety issues associated with off-road equipment. The results of that field survey were used as the underlying criteria to evaluate potential safety impacts of aftertreatment control installations on CHE.The population estimated to have safety issues would qualify for extensions under the 2005 rule.

1. *Future compliance for expired VDECS and experimental RTG crane VDECS (beyond 2014)*

The VDECS applied for compliance are estimated to last about 5 years. If a VDECS is retired before the piece of equipment is, the operator must either replace the filter or retire/replace the vehicle. The model estimates that these vehicles will continue to follow compliance options available in table ‘RegNonYTAssumptions’ (see coding and 3. Input Table Details below). Also, a small portion of RTG cranes have complied using experimental VDECS. These pieces of equipment are required to update to the latest VDECS in 2015 (see regulation order). The model replaces the experimental filter with a level 3 VDECS in that year.

1. **Non-Yard Truck Amendments (2011)**

As stated above, the amendments are coded within the procedure that runs the 2005 rule scenario. The baseline turnover methods and standing regulation compliance continue to follow the logic from above. There are four amendments implemented into the CHEI model: (1) Warranty replacement; (2) Family Emission Limit engine retrofits; (3) No VDECS extensions; and (4) Low Use extensions

1. *Warranty replacement*

The warranty replacement amendment allows operators to replace their equipment using a two year warranty provided by a manufacturer. The original rule requires operators to always replace with the ‘latest greatest’ equipment, even if a warranty replacement is available. The baseline attrition method includes a small amount of retirement for vehicles younger than two years. Although it is an extremely small number of equipment, this amendment was coded so that attrition would be stopped for the first two years of life. Stopping attrition is equivalent to replacing with the same model year in the emissions inventory. This method can be found in the ‘Attrition’ section of the ‘PopulationForecastRuleNonYT’ procedure under ‘Warranty Amendment’.

1. *Family Emission Limit (FEL) engine retrofits*

The Family Emission Limit amendment regards the portion of the population that have ‘alternative tier 4’ engines. These engines are officially considered part of the tier 4 population but have emissions equivalent to tier 3 engines. Staff estimates that potentially 20% of vehicles with model years between 2011 and 2015 can have alternative tier 4 engines. This amendment requires any operator with a FEL alternative engine to apply a VDECS even if it is part of the tier 4 family. This was coded in the ‘EmissionsRuleNonYT’ of the model. After the population is forecasted in the previous procedure, 20% of the engines with these model years are considered FEL engines and accounted for in the ‘T4AltPop’ designation.

1. *No VDECS Extensions*

Equipment operators that do not have the proper VDECS available are given a two year extension on their compliance dates (see (4) under Non-Yard Truck Regulation). This amendment provides an additional two year extension. The vehicles designated ‘NoVDECSPop’ in the model follow a separate compliance table titled ‘RegNonYTComp4YrExt’ under the amendments scenario.

1. *Low Use Extensions*

This amendment allows equipment being operated less than 200 hours annually to receive a two year extension. For the regulation these pieces of equipment must be designated ‘low use’. In the model, a portion of the vehicles are moved from the general population to the ‘LowUsePop’ designation. These vehicles are given the ‘RegNonYTComp2YrExt’ compliance schedule and are assigned 200 annual hours.

1. **Input Table Details**

The following list details all the input tables used in the CHEI model. Information is given for each table: table name (the name given in the CHEI model), function of the table, the procedure(s) and section(s) it is used, the relevant field name in the table is given in brackets, and a short description of how it is used. Placeholder tables and Join tables do not contain any information but allow the CHEI model to accomplish steps and store information more efficiently.

“2007 Calendar Years’ – Placeholder for base year

* Procedure/Section: ‘Loading’ sections of each population forecasting procedure Purpose: [Calendar Year] gives the population a base year field

‘ActivityCHE’ – Activity and cumulative hours for equipment types by age and location

Procedure: all three Emissions procedures

* Section: ‘Emissions for different equipment types’

Purpose: [CumulativeHours] helps calculate a deteriorated emissions factor, emission factors increase as a vehicle gets older (see code comments)

* Section: ‘Activity Annual’

Purpose: [Activity] annual activity for different equipment types by age and location are multiplied against emission factors ( [g/hour] \* [hours/year] = g/year ). Average activity is normalized to follow the growth rates (see code comments)

‘AgeDistributionLocationCat’ – Join table for locations and categories

* Procedure/Sections: all three Population Forecast procedures, many sections

Purpose: Table is used to join information that is *category* specific to the inventory which is location specific. (See ‘Turnover – (1) above about *categories* of equipment)

‘AgeDistributionLocationHP’ – Placeholder for ‘AttritionTotals’ – a temporary table

* Procedure/Section: PopulationForecastBaseline / IterationTables

Purpose: gives the totals table a placeholder for horsepower groups

‘AmendLowUseSSD’ – Sample of low use population

* Procedure/Section: PopulationForecastRuleNonYT / Amendment Pops

Purpose: The sample population is counted for a total count of vehicles that should be counted as ‘low use’ under the amendments scenario

‘AmendVisibilityIssue’ – Sample of NoVDECS for safety issues population

* Procedure/Section: PopulationForecastRuleNonYT / Amendment Pops

Purpose: The sample population is counted for a total count of vehicles that should be counted as ‘NoVDECS’ for safety issues under the amendments scenario

‘AttritionTable’ – Attrition rates and BAU distributions (see section 1 above). Also see ‘CHEI Inputs’ file for creating this table.

* Procedures: all three Population Forecasting procedures

Section: ‘Attrition’

Purpose: [OriginalAttrition] turnover rate by category and age

Section: ‘Purchasing’

Purpose: [Distribution] BAU distribution to guide purchasing

‘BaseYearPopulationTableAD’ – Population table for base year. See ‘CHEI Inputs’

* Procedures/Section: all three Population Forecasting procedures / ‘Loading’

Purpose: [VehiclePop] [O2Pop] [DOCPop] [NGPop] [OnRdPop] – these are the populations of different equipment types in the base year

‘EconomicAverageAges’ – average ages by category and calendar year. See ‘CHEI Inputs’

* Procedure/Section: PopulationForecastBaseline / EconomicAdjustment

Purpose: [AverageAge] guides age distribution through the recession

‘EmissionControlStrategies’ – Percent reduction in emissions for ‘ECS’ equipment

* Procedures/Section: all three Emissions procedures / ‘Emissions for different equipment types’

Purpose: [HC] [CO] [NOx] [PM] – multiplied against emission rates to get reduced emission factors

‘EmissionFactors’ – Emission factors and deterioration rates

* Procedures/Section: all three Emissions procedures / ‘Emissions for different equipment types’

Purpose: [THC] [CO] [NOx] [PM] [THCdr] [COdr] [NOxdr] [PMdr] – Emission factors are grams per horsepower-hour; deterioration rates [\*\*dr] increase emissions by a factor depending on the vehicles cumulative hours. Note: ‘THC’ is synonymous with ‘HC’

‘EmissionFactorsOnRd’ – Emission factors and deterioration rates for on-road vehicles

* Procedures/Section: EmissionsBaseline and EmissionsRuleYT/ ‘Emissions for different equipment types’

Purpose: [THC] [CO] [NOx] [PM] [THCdr] [COdr] [NOxdr] [PMdr] – same methodology as off-road.

‘EmissionFactorsT4Alt’ – Emission factors and deterioration rates for FEL engines

* Procedures/Section: EmissionsBaseline and EmissionsRuleNonYT/ ‘Emissions for different equipment types’

Purpose: [THC] [CO] [NOx] [PM] [THCdr] [COdr] [NOxdr] [PMdr] – same methodology as off-road.

*‘EmissionsInventoryFinal’ – Output Table*

*‘EmissionsOutput’ – Output Table*

‘FuelCorrectionFactorUpdate’ – Fuel Correction Factors by model year and horsepower

* Procedures/Section: all three Emissions procedures / ‘Emissions for different equipment types’

Purpose: [NOX] [PM] – multiplied against emission rates to correct for emission reductions due to diesel fuel emission changes. Note: HC correction factor = 0.72 applied to all equipment in coding rather than table.

‘GrowthFactorFinal’ – Growth for population and activity into the future. See ‘CHEI Inputs’

* Procedure/Section: all three Population Forecasting procedures / Growth

Purpose: [GrowthPop] growth for population each year. Multiplied against previous years population

* Procedure/Section: all three Emissions procedures / ActivityAnnual

Purpose: [GrowthActRelative] growth for activity relative to 2006. Activity is renormalized in the emissions model to these growth rates (see coding comments)

‘GrowthLocationID’ – Join table for growth factors and inventory

* Procedure/Section: Everywhere ‘GrowthFactorFinal’ is used

Purpose: [GrowthFactorFinal] contains generic location names, this table links them to the locations in the inventory

‘LoadFactorUpdate’ – Load factors by equipment type

* Procedures/Section: all three Emissions procedures / Emissions for different equipment types

Purpose: [Load Factor] multiplied against emission rates. The load factor is the percent of maximum power the different equipment types tend to run at.

‘Location\_COABDIS Table’ – Contains Air Basin that each location resides in

* Procedure/Section: User Form adds this after the model runs

‘RegNonYTAssumptions’ – Assumptions for non-yard truck compliance choices

* Procedure/Section: PopulationForecastRuleNonYT / ‘Regulation Influence’

Purpose: Percentages that equipment will comply by each compliance option each year. [Retire] – retirement without replacing; [Age 0] - replacement; [DPF] – apply emission control strategy; [AltFuel] – replace with alternative fueled vehicle (not counted in CHE inventory afterward)

‘RegNonYTComp’ – Percent of non-yard truck fleets that have to comply each year

* Procedure/Section: PopulationForecastRuleNonYT / ‘Regulation Influence’

Purpose: [Compliant] multiplied against base year population ‘BeginningPop’ to calculate how many vehicles need to comply each year. Note: attrition that takes place before using this table is counted as compliance (see coding comments)

‘RegNonYTComp2YrExt’ – Same as above but delayed two years for extensions

* Procedure/Section: PopulationForecastRuleNonYT / ‘Regulation Influence’

Purpose: [Compliant] – Under the 2005 rule a certain percentage of vehicles do not have proper control strategies available for compliance. These vehicles are given a two year extension.

‘RegNonYTComp4YrExt’ – Same as above but delayed four years for amendment

* Procedure/Section: PopulationForecastRuleNonYT / ‘Regulation Influence’

Purpose: [Compliant] – Under the 2011 amendment, vehicles that do not have emission control strategies available are given an addition two years beyond the extensions in the 2005 rule

‘RegYTComp’ – Percent of yard truck fleets that have to comply each year.

* Procedure/Section: PopulationForecastRuleYT / ‘Regulation Influence’
* Purpose: [Compliance] multiplied against base year population ‘BeginningPop’ to calculate how many vehicles need to comply each year. Yard Trucks under different categories get different compliance schedules (Onrd, Offrd, ECS–off-road with emission control strategies already on them) Note: attrition that takes place before using this table is counted as compliance (see coding comments)

‘TierID’ – Join table for ‘RegNonYTAssumptions’

* Procedure/Section: PopulationForecastRuleNonYT / ‘Regulation Influence’

Purpose: joins the non-yard truck assumptions to the inventory

‘TierOffroad’ – Tiers of equipment by horsepower and model year

* Procedure/Section: PopulationForecastRuleYT and PopulationForecastRuleNonYT / various sections

Purpose: [Tier] used to differentiate between tiers (only tier 4 and non-tier 4 are relevant) [Tier\_i] used to differentiate between tiers AND tier 4 interim. Depending on the step one of these is needed. (See coding comments)

‘Vehicle ID’ – Join table for equipment type names and ID numbers

* Various procedures and sections

Purpose: Stores equipment types in a more efficient way (storing IDs is smaller than the names)

1. **References**

(EPA, 2005) U.S. Environmental Protection Agency, *Calculation of Age Distributions in the Nonroad Model: Growth and Scrappage*, 2005 <http://nepis.epa.gov/Adobe/PDF/P1004L8U.PDF>

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