Yard Hostler Duty Cycle Summary
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*Introduction*

A yard hostler duty cycle has been developed as part of the Hybrid Yard Hostler Demonstration and Commercialization Project funded by the Port of Long Beach (POLB), the Port of Los Angeles (POLA), and the U.S. Environmental Protection Agency (EPA). The purpose of developing a yard hostler duty cycle is to be able to compare the relative emissions and fuel economy of hybrid yard hostlers vs. diesel yard hostlers at the chassis level. Note that there is currently no standard, chassis-level duty cycle specifically for yard hostlers.

The Center for Alternative Fuels, Engines and Emissions at West Virginia University (CAFEE) was contracted by CALSTART to develop the yard hostler duty cycle for this project. The duty cycle was developed based on in-use yard hostler data collected at the Long Beach Container Terminal (LBCT), a POLB tenant, between January 25$^{th}$ and January 30$^{th}$, 2008. LBCT is considered to be a "typical" small container handling terminal. (Note that container handling terminals can generally be grouped by size as either small, medium or large.)

This duty cycle was developed based on yard hostler operation in a marine terminal environment. It may also prove useful in representing other yard hostler applications, such as intermodal yards and/or distribution centers, however these applications have not been investigated sufficiently to make such a determination yet.

*Technical Considerations*

Yard hostlers are heavy-duty tractors used for moving cargo containers within port container terminals and other off-road areas. At any given time during the operation of a particular yard hostler, the physical load being pulled by the yard hostler can vary dramatically depending on the weights of the trailer and container connected to the tractor. In extreme cases, this weight difference can easily exceed 80,000 lbs. Therefore it is necessary to know both the vehicle speed and the physical load (weight) of the trailer and container being pulled by the yard hostler at any given time as both have a significant effect on how hard the engine has to work, (which in turn directly affects emissions and fuel consumption). While the use of data loggers to collect vehicle speed vs. time data is common, determination of the vehicle physical load (weight) vs. time added significant complexity to the real-time data collection procedures.

Another technical issue associated with the yard hostler application is that yard hostlers spend a significant portion of their operation in "creep" mode. "Creep" mode is informally defined as forward movement at speeds below 4 mph. (Note that 4 mph is approximately the lowest speed where the transmission can directly couple the engine speed to the drivetrain speed.) This frequently occurs while yard hostlers are waiting in a queue to have a cargo container loaded or unloaded. Since GPS-based data loggers typically do not have the resolution to distinguish "creep" operation vs. a stopped or idling vehicle, additional vehicle instrumentation was necessary to identify real-time "creep" operation to ensure that it would be adequately represented in the final yard hostler duty cycle. Note that the loads on the vehicle's propulsion and auxiliary systems can be significantly different during "creep" vs. idle operation, which may in turn affect emissions and fuel consumption.

*Yard Hostler Duty Cycle Statistics*

There are three main categories of work that yard hostlers perform: ship work, rail work and dock work (sometimes called yard work). Ship work and rail work involve a high degree of repetitive activities while dock work tends to involve more non-repetitive activities. In addition, ship and rail work constitute the vast majority of all yard hostler activities at LBCT (about 95%). For these reasons, in-use data collection at LBCT focused on ship and rail activities, purposely excluding dock work activities. A summary of the key statistics associated with the yard hostler in-use data collected at LBCT is given below:

| *Parameter* | *All Activities* | *Rail Only* | *Ship Only* |
|---|---|---|---|
| Avg. Speed | 7.5 mph | 8.9 mph | 7.0 mph |
| Std. Dev. Speed | 3.4 mph | 4.2 mph | 3.2 mph |
| Creep | 21.4% | 15.1% | 23.3% |
| Idle | 40.1% | 31.7% | 41.8% |
| Creep + Idle | 61.5% | 46.8% | 65.1% |

*Yard Hostler Weight Categories*

As a result of the significant variability in physical load (weight) of the yard hostler during operation and the constraints of typical heavy-duty chassis dynamometers, the yard hostler duty cycle was split into two (2) sub-cycles. Each sub-cycle corresponds to that portion of the yard hostler duty cycle associated with yard hostler operation in one of two (2) weight categories: medium-heavy duty and heavy-heavy duty. The "dividing line" between the medium-heavy duty and heavy-heavy duty weight categories was chosen as a Gross Combined Vehicle Weight (GCVW) of 20,040 kg. (44,181 lbs.). The choice of this "dividing line" was based on an analysis of the combined vehicle, trailer and container weights of all potential tractor/trailer combinations. Average weights for each category were then calculated based on actual data as the number of pound-trips in each category divided by the total number of trips in each category. The results are as follows:

Average weight for medium-heavy duty category: 11,888 kg. (26,209 lbs.)
Average weight for heavy-heavy duty category: 32,837 kg. (72,393 lbs.)

From the yard hostler in-use data collection, the actual percentage of time spent in each weight category was as follows:

Percentage of time in medium-heavy duty category: 64.1%
Percentage of time in heavy-heavy duty category: 35.9%

A summary of the key statistics associated with each weight category (i.e., combining rail and ship activities in each weight category) vs. the statistics for all activities is given below:

| *Parameter* | *All Activities* | *Medium-Heavy (Rail + Ship)* | *Heavy-Heavy (Rail + Ship)* |
|---|---|---|---|
| Avg. Speed | 7.5 mph | 7.3 mph | 7.7 mph |
| Std. Dev. Speed | 3.4 mph | 3.4 mph | 3.4 mph |
| Creep | 21.4% | 25.6% | 13.9% |
| Idle | 40.1% | 44.4% | 30.6% |
| Creep + Idle | 61.5% | 70.0% | 44.5% |

*Yard Hostler Sub-Cycles*

The time-speed traces for the medium-heavy duty and heavy-heavy duty sub-cycles can be found in the file, “Yard Hostler Driving Cycles.xls”. Each sub-cycle is composed of individual microtrips taken directly from the data collected during in-use yard hostler operation. A microtrip was defined as a distinct activity starting with the vehicle at rest (idling or stopped), then accelerating to a speed greater than creep speed (i.e., greater than 4 mph), and then coming to rest again. There are two sub-cycles, one representing medium-heavy duty operation and the other representing heavy-heavy duty operation. Each sub-cycle is 1200 sec. in duration with the first 300 seconds consisting of rail microtrips followed by the last 900 seconds of ship microtrips. This corresponds to the estimated split between yard hostler rail (25%) vs. ship (75%) activities at LBCT. A summary of the key microtrip statistics (excluding creep and idle) associated with each portion (rail vs. ship) of the sub-cycles is as follows:

| *Parameter* | *Medium-Heavy Rail* | *Medium-Heavy Ship* | *Heavy-Heavy Rail* | *Heavy-Heavy Ship* |
|---|---|---|---|---|
| Duration | 300 sec. | 900 sec. | 300 sec. | 900 sec. |
| Avg. Speed | 9.2 mph | 6.8 mph | 8.4 mph | 7.6 mph |
| Std. Dev. Speed | 4.4 mph | 3.3 mph | 3.9 mph | 3.5 mph |
| Creep | 21.5% | 27.8% | 6.7% | 16.5% |
| Idle | 47.3% | 42.1% | 14.3% | 29.4% |
| Creep + Idle | 68.8% | 69.9% | 21.0% | 45.9% |

A summary of the overall statistics (including creep and idle) associated with the medium-heavy duty sub-cycle is as follows:

| *Parameter* | *Medium-Heavy Rail* | *Medium-Heavy Ship* | *Medium-Heavy Combined* |
|---|---|---|---|
| Duration | 300 sec. | 900 sec. | 1200 sec. |

| | | | |
|---|---|---|---|
| Avg. Speed | 6.1 mph | 5.0 mph | 5.3 mph |
| Std. Dev. Speed | 7.8 mph | 6.4 mph | 6.8 mph |
| Creep | 13.7% | 16.9% | 16.1% |
| Idle | 44.5% | 41.2% | 42.0% |
| Creep + Idle | 58.2% | 58.1% | 58.1% |

A summary of the overall statistics (including creep and idle) associated with the heavy-heavy duty sub-cycle is as follows:

| *Parameter* | *Heavy-Heavy Rail* | *Heavy-Heavy Ship* | *Heavy-Heavy Combined* |
|---|---|---|---|
| Duration | 300 sec. | 900 sec. | 1200 sec. |
| Avg. Speed | 7.1 mph | 7.1 mph | 7.1 mph |
| Std. Dev. Speed | 5.2 mph | 6.9 mph | 6.5 mph |
| Creep | 17.6% | 13.9% | 14.9% |
| Idle | 13.3% | 28.4% | 24.6% |
| Creep + Idle | 30.9% | 42.3% | 39.5% |

*Chassis Dynamometer Testing*

Since actual yard hostler operations includes activities in both the medium-heavy duty and heavy-heavy duty weight categories, chassis dynamometer testing of yard hostlers must include tests of both the medium-heavy duty and heavy-heavy duty sub-cycles. Results from both cycles can then be combined mathematically to produce a single, aggregate result for yard hostler emissions and fuel economy. The medium-heavy duty sub-cycle is tested at the average weight for the medium-heavy duty weight category while the heavy-heavy duty sub-cycle is tested at the average weight for the heavy-heavy duty weight category. The results for each sub-cycle are then weighted according to the overall percentage of time spent in each weight category.

Since both sub-cycles have the same overall duration and ratio of rail to ship activity (time), it is not necessary to scale the results before combining them. Given that testing is performed at the chassis (vs. engine) level, emissions results are reported in grams/hour (g/hr) rather than grams/brake horsepower-hr (g/bhp-hr). Due to the significant percentage of idle and creep in the yard hostler duty cycle, fuel economy results are reported in gallons/hour (gal/hr) rather than miles per gallon (mpg). Note that this is consistent with standard practice in the yard hostler industry where fuel economy is generally reported in gal/hr and vehicles are typically equipped with engine-hour meters rather than odometers.

*Example Calculation of Emission Factors*

Emissions from medium-heavy duty rail: 12 g/hr
Emissions from medium-heavy duty ship: 15 g/hr
Emissions from heavy-heavy duty rail: 20 g/hr
Emissions from heavy-heavy duty ship: 22 g/hr

Emissions Factor =

$((emissions_{medium\text{-}heavy\ rail}) \times (\%_{rail}) \times (\%_{medium\text{-}heavy})) +$
$((emissions_{medium\text{-}heavy\ ship}) \times (\%_{ship}) \times (\%_{medium\text{-}heavy})) +$
$((emissions_{heavy\text{-}heavy\ rail}) \times (\%_{rail}) \times (\%_{heavy\text{-}heavy})) +$
$((emissions_{heavy\text{-}heavy\ ship}) \times (\%_{ship}) \times (\%_{heavy\text{-}heavy})) =$
((12 g/hr) x (0.25) x (0.641)) +
((15 g/hr) x (0.75) x (0.641)) +
((20 g/hr) x (0.25) x (0.359)) +
((22 g/hr) x (0.75) x (0.359)) =
(1.92 g/hr + 7.21 g/hr + 1.78 g/hr + 5.92 g/hr) =
16.83 g/hr

Note that it is also possible to mathematically adjust the emissions factors calculations for different ratios of rail vs. ship activities.

*Example Calculation of Fuel Economy*

| | |
|---|---|
| Fuel consumption from medium-heavy duty rail: | 0.75 gal/hr |
| Fuel consumption from medium-heavy duty ship: | 1.0 gal/hr |
| Fuel consumption from heavy-heavy duty rail: | 2.0 gal/hr |
| Fuel consumption from heavy-heavy duty ship: | 2.2 gal/hr |

Fuel Economy =

$((fuel_{medium\text{-}heavy\ rail}) \times (\%_{rail}) \times (\%_{medium\text{-}heavy})) +$
$((fuel_{medium\text{-}heavy\ ship}) \times (\%_{ship}) \times (\%_{medium\text{-}heavy})) +$
$((fuel_{heavy\text{-}heavy\ rail}) \times (\%_{rail}) \times (\%_{heavy\text{-}heavy})) +$
$((fuel_{heavy\text{-}heavy\ ship}) \times (\%_{ship}) \times (\%_{heavy\text{-}heavy})) =$
((0.75 gal/hr) x (0.25) x (0.641)) +
((1.0 gal/hr) x (0.75) x (0.641)) +
((2.0 gal/hr) x (0.25) x (0.359)) +
((2.2 gal/hr) x (0.75) x (0.359)) =
(0.12 gal/hr + 0.48 gal/hr + 0.18 gal/hr + 0.59 gal/hr) =
1.37 gal/hr

Note that it is also possible to mathematically adjust the fuel economy calculations for different ratios of rail vs. ship activities.