CAFEE

Center for Alternative Fuels, Engines & Emissions

West Virginia University

Final Report

DEVELOPMENT OF A YARD HOSTLER ACTIVITY CYCLE

Submitted to:

Brad Rutledge
Senior Project Manager, CALSTART Florida Office
801 SE 16th Court, #6, Fort Lauderdale, FL 33316
Phone: (954) 767-8196, Fax: (626) 744-5610
www.calstart.org

Center for Alternative Fuels, Engines & Emissions
Dept. of Mechanical & Aerospace Engineering
West Virginia University
Morgantown WV 26506-6106

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INTRODUCTION

The Center for Alternative Fuels, Engines and Emissions at West Virginia University worked with CALSTART to develop driving cycles representative of yard hostler activity at the Long Beach Container Terminal (LBCT) at the Port of Long Beach. While the driving cycles were developed from LBCT yard hostler activity, these cycles may be applicable to other container terminals but differences in activity and loading between LBCT and the yard being considered must be examined.

The researchers utilized a proven technique to generate representative driving cycles from in-use activity data where the driving cycles are constructed using actual vehicle speed-time data. This technique involved logging speed-time and idling data from yard hostlers as they carried out their daily activities. The data was then broken into microtrips with each microtrip composed of a period of idle followed by the vehicle travelling some distance and returning to idle. Each microtrip was then classified according to the type of activity the vehicle was performing (e.g., ship unloading) and the vehicle loading. The data set was evaluated to determine percentage of time spent in each activity and statistical metrics were calculated for each activity/loading data subsets. Groups of driving cycles representing ship related activity at medium-heavy and heavy-heavy loading and rail related activity at medium-heavy and heavy-heavy loading were then generated by randomly combining microtrips from respective data sets. These individual driving cycles were then compared to their parent datasets using statistical metrics and a minimization function to choose the most representative driving cycle from each group.

DATA LOGGING

Two identical Kalmar Ottawa 4x2 terminal tractors (utility tractor rigs/UTR's or "yard hostlers") operating at the Long Beach Container Terminal, Inc, Port of Long Beach, California, (LBCTI) were instrumented with data loggers to record various operations pertinent to container handling. The yard hostlers then performed a suite of tasks involving the movement of containers using either a cornerless gathering chassis, known colloquially as a "bomb-cart", or with the containers mounted securely onto a road-worthy frame, referred to as a "chassis". These movements were conducted throughout the terminal over 14 shifts from January 25th through January 30th, 2008. Position, speed, time, acceleration, and driveshaft frequency data were accumulated during this period. Details of the data logging effort are contained in the research program's Interim Report submitted to CALSTART.

Automated Logging

Two identical data logging systems were assembled. Each system was constructed around a Race Technologies DL-1 data logger. Speed and position data was acquired by the internal GPS receiver, a driveshaft movement detector, and other analog voltage inputs.

In order to differentiate between the UTR creeping very slowly and actually stopped, a drive shaft movement detector was designed. This consisted of a pickup coil mounted near two magnets attached to the UTR's drive shaft. The signal from the coil was then fed to an amplifier and recorded on one of the DL-1 logger's analog inputs, while the "squared up" signal from the amplifier was fed to a frequency input channel on the DL-1.

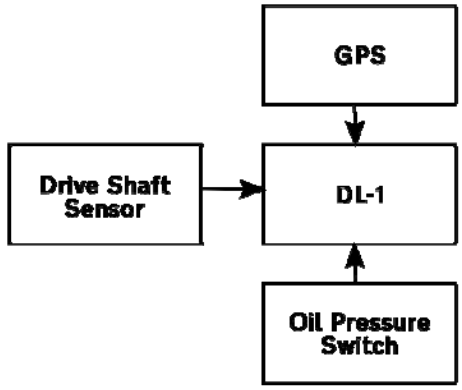

Figure 1 - Automated data logging system block diagram.

Since vehicle emissions were of primary concern, a method separate from positional logging was required such that idle periods could be identified for inclusion in the representative test cycles. The data logging system was equipped to determine idling periods though input from the engine oil pressure switch. Use of the oil pressure switch was necessary as an energized ignition system implies solely that the vehicle is energized (“key-on”) while the oil pressure switch gave a positive indication that the engine is operating.

Manual Logging

Each driver of the instrumented UTRs was in radio communication with a WVU researcher, located in the boardroom on the second floor of the LBCTI administration building with a commanding view of the terminal. The driver reported what activity they were engaged in and when he/she changed the type of trailer/load combination while the researchers recorded the reported information. As each report from the driver was entered into the laptop, it was automatically “time-stamped” with the UTC (universal coordinated time) signal from its respective GPS receiver. As a backup, the communication and the time it was received was also noted on a paper logging sheet.

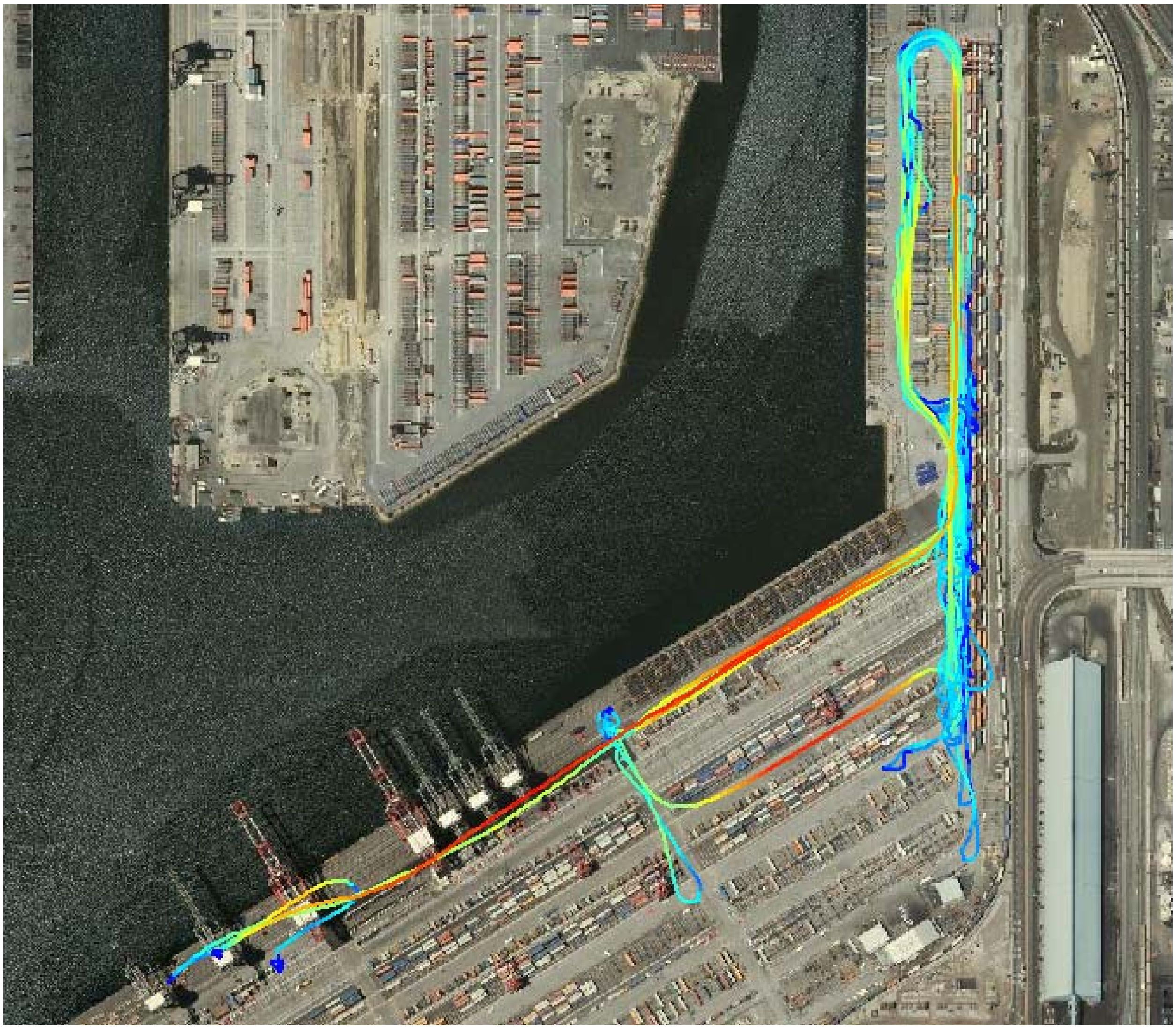

Figure 2 - Aerial view of LBCTI, showing the track taken by a yard hostler performing "rail unloading" operations.

DATA PROCESSING

The data processing operation involved removing inaccurate/incomplete data, breaking the speed-time/idle data into microtrips, incorporating the speed-time/idle data with the manually recorded activity/loading data, identifying creep operation and computing statistical metrics.

Removal of Inaccurate/Incomplete Data

The quality of data collected using GPS receivers is subject to the number of satellites with which the receiver can communicate. At a minimum, the receiver must receive information from three satellites to infer longitude and latitude and four satellites to infer altitude. When the vehicle carrying the GPS travels under or around an object such as an overhead crane that obstructs and interrupts communication between the GPS and satellites, the positional data becomes suspect. In cases where a small number of data points were lost, the missing section could be reconstructed using data from the preceding and following section. Fortunately, for this research, a more than sufficient number of satellites were always in communication.

Determination of Idle

Determining idle operation proved problematic since the prototype driveshaft position sensor did not always work properly. As a result, positional data from the GPS had to be utilized to determine idle. Since noise in the GPS signals would always result in a slightly positive speed indication, an algorithm was developed that established a GPS speed threshold based on the number of satellites in view. The threshold value was typically 0.1 mph when the vehicles were idling in the yard and clear of any overhead obstructions but rose as high as 0.5 mph when the vehicles were under yard cranes. The data was processed such that data points where speed was below this threshold were considered idle points.

Determination of Vehicle Creep Mode Operation

Emissions and performance during creep operation are sufficiently different from those during idle or normal operation which made it necessary to both identify creep operation and use the percentage of time spent in creep mode as a comparative metric. Vehicle creep is defined as when the vehicle is moving forward in first gear without the accelerator pedal being depressed. This type of operation typically occurs when a vehicle is waiting in traffic or a line. With vehicles equipped with automatic transmissions, creep occurs when the operator takes their foot off the brake pedal and allows the vehicle to move forward without depressing the accelerator pedal. For vehicles equipped with manual transmissions, creep is defined as operation when the operator releases the brake and partially or fully engages the clutch to move the vehicle forward without depressing the accelerator pedal. The yard hostlers at LBCT were equipped with automatic transmissions where, during creep operation, vehicle speed was less than 4 mph.

Processing into Microtrips

The continuous speed-time/idle data was processed into individual microtrips with each microtrip consisting of a period of idle followed by a trip of some distance followed by a return to idle. Statistical metrics including idle duration, microtrip average speed and average standard deviation of speed were then calculated for each individual microtrip.

The final step in processing the data was to identify both the activity and loading for each microtrip. This was accomplished by cross referencing the speed-time/idle data with the separately logged activity and loading data.

ACTIVITY CLASSIFICATION

CALSTART proposed the following activity classifications with their respective three letter acronym be utilized for this research:

- Ship work
    - Ship loading
        - Bomb cart, full container – SL1
        - Chassis, full container – SL2
        - Bomb cart, empty container – SL3
    - Ship unloading
        - Bomb cart, full container – SU1
        - Chassis, full container – SU2
- Rail work
    - Rail loading
        - Chassis, full container – RL2
    - Rail unloading
        - Bomb cart, full container – RU1
        - Chassis, full container – RU2
        - Bomb cart, empty container – RU3
        - Chassis, empty container – RU4

In practice, RU1 was not encountered as containers were not typically unloaded from rail cars using bomb carts. The original estimates percentage of time the LBCT yard hostler fleet spent performing the various activities are shown in

Table 1.

Table 1 – LBCT Estimated Activity Classifications

Activity	%	Sub-Activity	%	Configuration	%	Total %
Ship Work	75	Loading	50	SL1	20	7.5
				SL2	15	5.6
				SL3	65	24.4
		Unloading	50	SU1	75	28.1
				SU2	25	9.4
Rail Work	20	Loading	65	RL2	100	13
		Unloading	35	RU1	10	0.7
				RU2	40	2.8
				RU3	35	2.5
				RU4	15	1

A third classification, namely "dock work", made up the remaining 5% of activity but was not considered for cycle generation.

Table 2 - Metrics from data logged at POLB

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%

For driving cycle generation, vehicle activity was classified into two major categories, namely that activity related to ship loading/unloading and that related to rail loading/unloading. Based on data logged by WVU, ship and rail related activity represented 77% and 23% of the observed activity duration after disregarding miscellaneous yard work activity. For the activity monitored during this project, the vehicles spent 64.1% of their time in medium-heavy duty classified operation and 35.9% in heavy-heavy duty operation.

Vehicle Loading

Vehicle loading was determined by combining the weight of the vehicle, the weight of the trailer (if present), and the weight of any container. Two different types of trailers, a simple chassis and a cornerless gathering chassis (CGC), were used in the port. The simple chassis was equipped with mounting points on the corners to receive a container and were typically used if the containers were to be transferred off-site using an over-the-road tractor. The cornerless gathering chassis, also known as a bomb cart, was used in cases where the containers were going to be immediately transferred to a rail car or if they were going to be stored at the yard while awaiting transfer. Unloaded or empty container weights were provided by LBCT while loaded container weights were determined from container load data. For the data analysis process, loaded container data provided by the port operators were estimated by LBCT to be 17,450 kg for loaded 20 ft containers and 22,725 kg for loaded 40 foot containers. Table 3 contains the weights of individual components and the weights of the combinations considered from the observed data.

Table 3 - Component Masses

Component	Component Mass (kg)	Total Mass w/Simple Chassis (kg)	Total Mass w/Bomb Cart (kg)
Tractor	6,440	-	-
Simple Chassis	2,950	9,390	-
CGC (Bomb-cart)	9,750	-	16,190
Empty Container – 20 foot	2,200	11,590	18,390
Empty Container - 40 foot	3,850	13,240	20,040
Full Container – 20 foot	17,450*	26,840	33,640
Full Container - 40 foot	22,725*	32,115	38,915

* - Estimated by LBCT

Loading classification was defined as either medium-heavy or heavy-heavy with the medium-heavy classification covering those periods of activity where the vehicle was operating without a full container (≤ 20,040 kg) and the heavy-heavy covering periods of activity with a full container (> 20,040 kg). This classification was done to classify or bin the data for analysis. Simulated vehicle masses for emissions and performance testing were determined to be 11,888 kg and 32,837 kg, respectively, for the medium-heavy and heavy-heavy cycles. These masses were determined through the use of activity weighting factors and activity loading. The weighting factors took into account the percentage makeup of trips in each activity classification compared to that of the total trips in the applicable general activity classification (medium-heavy/heavy-heavy).

Table 4 - Number of microtrips and average vehicle load in each activity classification

Activity Classification	Number of Microtrips	Average Load(kg)
All	4000	18,860
All Medium-Heavy	2764	12,897
All Heavy-Heavy	1236	32,193
All Rail	679	20,044
Medium-Heavy Rail	461	13,123
Heavy-Heavy Rail	218	34,678
All Ship	3321	18,618
Medium-Heavy Ship	2303	12,852
Heavy-Heavy Ship	1018	31,661

It was initially proposed that this research would result in the creation of either two test cycles representing ship and rail activity or four test cycles representing ship loading, ship unloading, rail loading, and rail unloading. The difference between loading and unloading activity was not significant and, as such, the option of creating four test cycles was not exercised. However, since vehicle loading has a significant impact on both emissions and fuel economy, individual test cycles for rail and ship activity would not be sufficient to characterize emissions and fuel economy. A determination was made that two test cycles, one representing medium-heavy activity and one representing heavy-heavy activity would be generated with the first 25% of each test cycle representing rail activity and the final 75% representing ship activity. This would allow for the evaluation of vehicles in four separate load+activity categories.

STATISTICAL METRICS

Statistical metrics were calculated based on individual microtrips and on groups of microtrips which composed either driving cycles or activity datasets. The following metrics were calculated for individual microtrips:

- Average Speed ($\overline{v}$): Average speed while vehicle was in motion (excludes idle time). Standard Deviation of Speed ($\overline{\sigma}$): Standard deviation of speed while vehicle was in motion (excludes idle time).

- Idle Duration ($\%_{idle}$): The percentage of the microtrips duration spent idling.

For groups of microtrips, which included activity datasets and derived driving cycle, the following metrics were calculated:

- Average Microtrip Average Speed ($\overline{v}_{ave}$): The average of the average microtrip speed (v_{ave}) for the microtrips in the group.

- Average Microtrip Standard Deviation of Microtrip Speed ($\overline{\sigma}_{ave}$): The average of the standard deviation of speed for the microtrips in the group.

- Percent Idle ($\%_{idle}$): Percentage of time spent idling in relation to the group duration. Percent Creep ($\%_{creep}$): Percentage of time spent operating in creep mode in relation to the group duration.

Minimization Function

In order to compare how well candidate cycles represented the characteristics of activity group it was derived from, a minimization function was developed based on the group metrics of average microtrip average speed ($\overline{v}_{ave}$), average microtrip standard deviation of speed ($\overline{\sigma}_{ave}$), percentage of group/cycle duration at idle ($\%_{idle}$) and percentage of group/duration spent in creep mode ($\%_{creep}$). After combining individual microtrips from an activity group together to form a candidate cycle, the percent difference between the group metrics of the candidate cycle and those of the activity group were determined using Equations 1-4. In each case, the smaller the difference between the group metric for the candidate cycle and that of the activity group indicated how representative that candidate cycle was to the activity group with regards to the metric being considered.

$$m_v = \left[\frac{(v_{ave})_{Cycle} - (v_{ave})_{Dataset}}{(v_{ave})_{Dataset}} \right] \qquad \textbf{Equation 1}$$

$$m_{\sigma} = \left[\frac{(\sigma_{ave})_{Cycle} - (\sigma_{ave})_{Dataset}}{(\sigma_{ave})_{Dataset}} \right]$$ **Equation 2**

$$m_{\%idle} = \left[\frac{(\%_{idle})_{Cycle} - (\%_{idle})_{Dataset}}{(\%_{idle})_{Dataset}} \right]$$ **Equation 3**

$$m_{\%creep} = \left[\frac{(\%_{creep})_{Cycle} - (\%_{creep})_{Dataset}}{(\%_{creep})_{Dataset}} \right]$$ **Equation 4**

The differences calculated using Equations 1-4 were then combined using Equation 5 which provided an overall comparative metric m. When comparing how well a group of candidate cycles compared to their parent activity group, that candidate cycle with a value of m closest to zero was deemed the best representation of the activity group.

$$m = \sqrt{m_V^{\ 2} + m_{\sigma}^{\ 2} + m_{\%idle}^{\ 2} + m_{\%creep}^{\ 2}}$$ **Equation 5**

An example of utilizing the minimization function to select the most representative candidate cycle from a group of candidate cycles for an activity is illustrated in Table 5.

Table 5 - Comparative minimization function data for medium-heavy rail cycle generation.

Candidate Cycle ID	$\overline{V}_{ave}$ (mph)	$\overline{\sigma}_{ave}$ (mph)	$\%_{creep}$	$\%_{idle}$	$\%_{creep+idle}$	m
Parent Group	8.5766	3.9269	6.4483	14.4176	20.86597	
9	8.3767	3.9325	6.7057	14.3415	21.04719	0.080551
365	8.0061	3.8462	5.2232	15.5009	20.72411	0.203288
256	8.1333	3.7326	5.1110	15.0786	20.18955	0.223514
122	8.4320	3.5466	6.5539	19.0200	25.57383	0.233784
209	8.5951	3.3527	7.5619	16.745	24.30690	0.236997
99	7.5957	3.2609	5.888	13.7576	19.64558	0.245915
226	7.5410	3.8408	5.0094	15.4121	20.42146	0.25467
148	7.3058	3.1019	6.6049	14.7203	21.32516	0.259588
467	7.8746	3.8571	5.1103	12.2632	17.37348	0.285268
246	7.7192	4.2072	5.1402	11.6005	16.74073	0.311766

Table 5 shows comparative metrics from the ten most representative candidate cycles of a total of five hundred candidate cycles generated along with the comparative metrics of the parent activity group (in this case medium-heavy rail activity). The table also contains the minimization function (m) for each candidate cycle. In this case, candidate cycle number nine was selected as, based on the minimization function, most representative of the parent activity group.

Candidate Cycle Duration

A duration of 1200 seconds for the candidate cycles was chosen based on typical lengths for other heavy-duty vehicle driving cycles. The chosen duration also provides a balance between having an excessively long cycle and providing sufficient fuel consumption and emissions for evaluation purposes. The target duration for the candidate cycles, calculated as the sum of the durations of the individual microtrips used to compose each candidate cycle, was less than 1200 seconds to allow for thirty seconds (30) of idle at the beginning and end of each chassis test. The additional time is necessary to allow for stabilization at the beginning of each chassis test and allows for the lag time in response between the emissions analyzers and chassis activity at the end of the cycle. The additional idle time was taken into account during comparison with the minimization function.

Candidate Cycle Generation and Selection

For each activity-loading pair, five hundred candidate cycles were generated and evaluated against the activity-loading pair data set using the minimization function. For rail related activity, the candidate cycles had durations of 300 seconds while the ship related activity cycles were 900 seconds. The metrics for the target and selected candidate cycles for each activity are shown in Table 6. The selected medium-heavy and heavy-heavy rail loading cycles were then combined with the respectively loaded ship cycles to form the final medium-heavy and heavy-heavy test cycles which are presented in Figure 3 and Figure 4.

Table 6 - Microtrip metrics for target and selected candidate cycles.

	Average Speed (mph)	St. Dev Speed (mph)	% Creep	% Idle	Minimization Function (see eqn. 5)
Target Medium-Heavy Rail	9.101	4.290	19.7	43.6	
Selected Medium-Heavy Rail	9.177	4.415	21.5	47.3	0.0997
Target Medium-Heavy Ship	6.767	3.153	27.4	42.4	
Selected Medium-Heavy Ship	6.844	3.310	27.8	42.1	0.0576
Target Heavy-Heavy Rail	8.577	3.927	6.4	14.4	
Selected Heavy-Heavy Rail	8.377	3.933	6.7	14.3	0.0806
Target Heavy-Heavy Ship	7.391	3.279	16.0	27.3	
Selected Heavy-Heavy Ship	7.634	3.453	16.5	29.4	0.0861

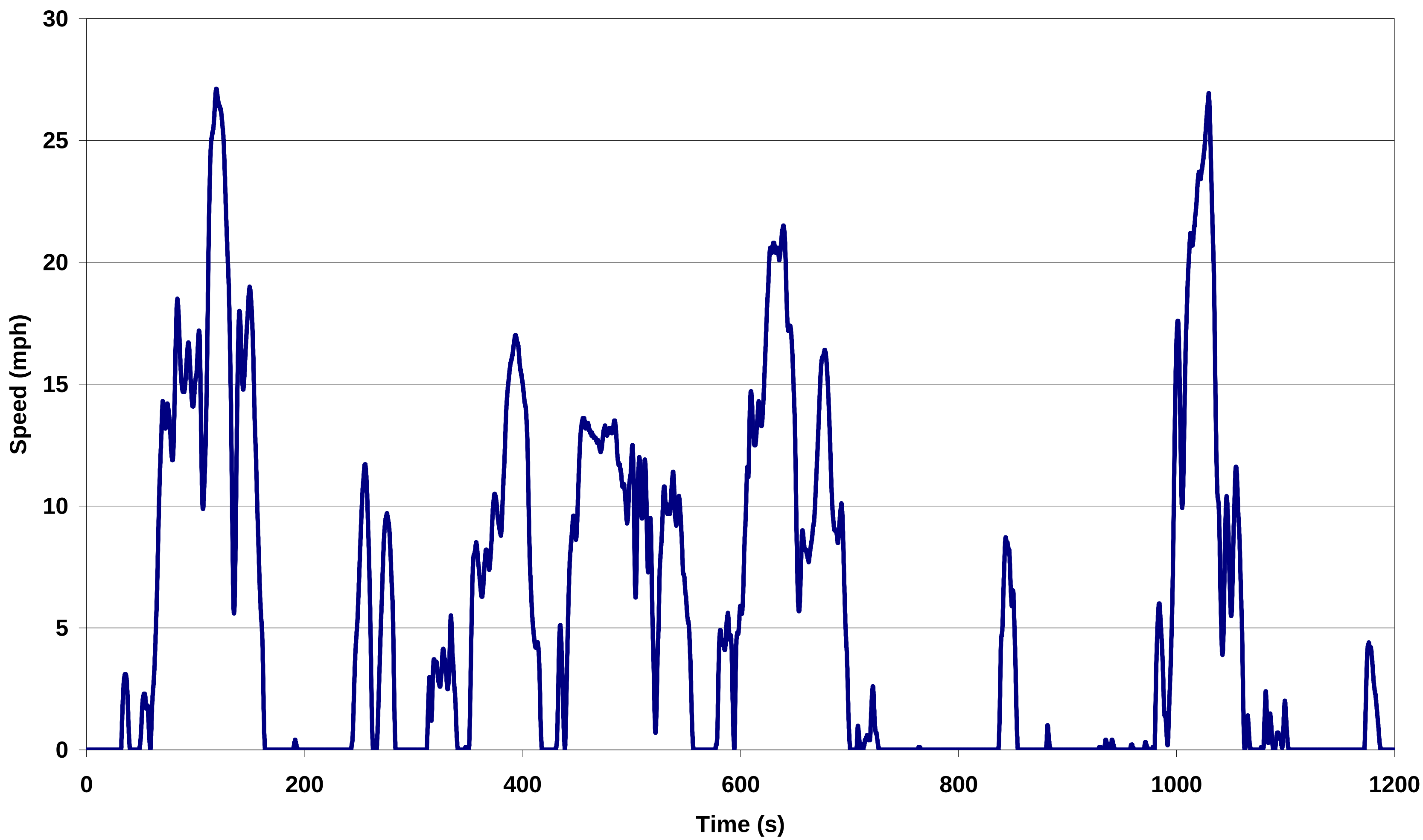

Figure 3 - Medium-Heavy Yard Hostler Driving Cycle

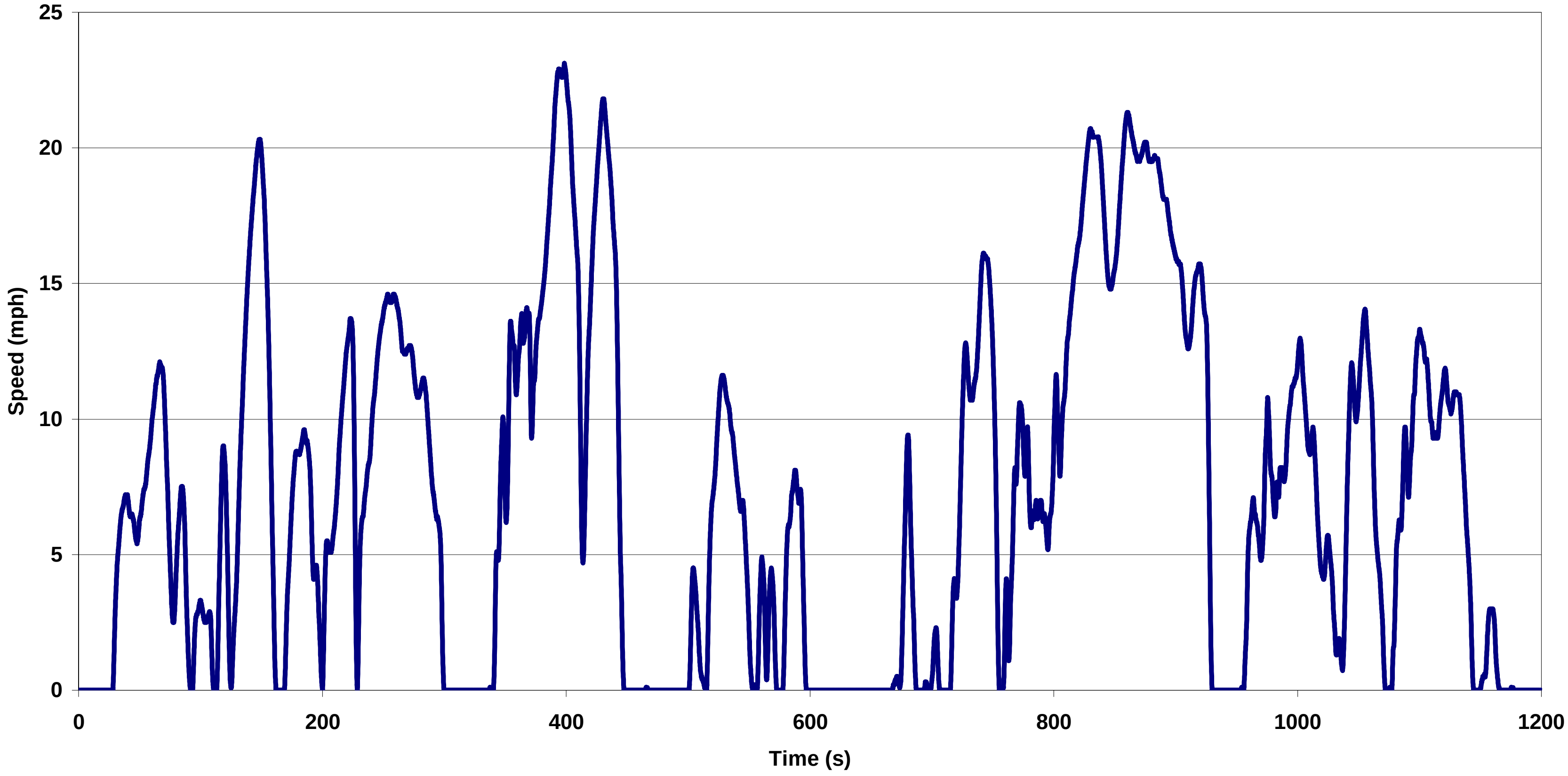

Figure 4 - Heavy-Heavy Yard Hostler Driving Cycle

Table 7 and Table 8 show the overall statistics for the medium-heavy and heavy-heavy cycles. Please note that the overall statistics were calculated considering each section of the driving cycles, including idle, rather than the statistics of individual microtrips.

Table 7 – Overall statistics for the medium-heavy duty test cycle.

Parameter	***Medium-Heavy Rail***	***Medium-Heavy Ship***	***Medium-Heavy Combined***
Duration	300 sec.	900 sec.	1200 sec.
Avg. Speed	6.12 mph	4.99 mph	5.28 mph
Std. Dev. Speed	7.83 mph	6.39 mph	6.79 mph
Percent Creep Duration	13.7%	16.9%	16.1%
Percent Idle Duration	44.5%	41.2%	42.0%
Percent Creep + Idle Duration	58.2%	58.1%	58.1%

Table 8 – Overall statistics for the heavy-heavy duty test cycle.

Parameter	***Heavy-Heavy Rail***	***Heavy-Heavy Ship***	***Heavy-Heavy Combined***
Duration	300 sec.	900 sec.	1200 sec.
Avg. Speed	7.13 mph	7.11 mph	7.12 mph
Std. Dev. Speed	5.15 mph	6.87 mph	6.48 mph
Percent Creep Duration	17.6%	13.9%	14.9%
Percent Idle Duration	13.3%	28.4%	24.6%
Percent Creep + Idle Duration	30.9%	42.3%	39.5%

Emissions and Fuel Economy Evaluation with Developed Cycles

Aggregating or apportioning emissions and fuel economy results from individual tests can be accomplished such that the impact of the fleet, changes in fleet makeup or changes in activity can be evaluated. This is accomplished by weighting the results from each test cycle or activity section of each test cycle.

As an example, consider the following particulate matter emissions results from chassis testing of a yard hostler using the cycles developed in this program:

Medium Heavy Rail: 12 grams per hour
Medium-Heavy Ship: 15 grams per hour
Heavy-Heavy Rail: 20 grams per hour
Heavy-Heavy Ship: 22 grams per hour

In addition, consider the case of POLB where vehicles spend 64.1% of their time in medium-heavy configuration and 35.9% in heavy-heavy configuration and 25% of their time is spent in rail related operation while 75% is spent on ship related activity. The aggregate emissions/consumption rate (ER/CR) for a vehicle operating under the conditions the cycles were derived under would be calculated by multiplying the emissions rate during each activity by the percentage of time spent in that activity and summing the results.

$ER = ER_{medium\text{-}heavy\ rail} * (\%_{rail} * \%_{medium\text{-}heavy}) + ER_{medium\text{-}heavy\ ship} * (\%_{ship} * \%_{medium\text{-}heavy}) + ER_{heavy\text{-}heavy\ rail} * (\%_{rail} * \%_{heavy\text{-}heavy}) + ER_{heavy\text{-}heavy\ ship} * (\%_{ship} * \%_{heavy\text{-}heavy})$

ER = 12 g/hr * (25% * 64.1%) + 15 g/hr * (75% * 64.1%) + 20 g/hr * (25% * 35.9%) + 22 g/hr * (75% * 35.9%)

ER = 1.92 g/hr + 7.21 g/hr + 1.78 g/hr + 5.92 g/hr

= 16.83 g/hr

In the case of fuel consumption, consider the same percentage activity breakdown with measured fuel consumption for each activity as follows:

Medium Heavy Rail: 0.75 gallons per hour
Medium-Heavy Ship: 1.0 gallons per hour
Heavy-Heavy Rail: 2 gallons per hour
Heavy-Heavy Ship: 2.2 gallons per hour

$CR = CR_{medium\text{-}heavy\ rail} * (\%_{rail} * \%_{medium\text{-}heavy}) + CR_{medium\text{-}heavy\ ship} * (\%_{ship} * \%_{medium\text{-}heavy}) + CR_{heavy\text{-}heavy\ rail} * (\%_{rail} * \%_{heavy\text{-}heavy}) + CR_{heavy\text{-}heavy\ ship} * (\%_{ship} * \%_{heavy\text{-}heavy})$

CR = 0.75 gal/hr * (25% * 64.1%) + 1.0 gal/hr * (75% * 64.1%) + 2 gal/hr * (25% * 35.9%) + 2.2 gal/hr * (75% * 35.9%)

ER = 0.12 gal/hr + 0.48 gal/hr + 0.18 gal/hr + 0.59 gal/hr

= 1.37 gal/hr

If the percentage of rail and ship related activities changed, aggregate emissions/consumption rates could be calculated using the same fashion. For example, if the percentage of rail activity increased to 40% and the split between medium-heavy and heavy-heavy activity remained the same, the aggregate particulate emissions rate would be:

$ER = ER_{medium\text{-}heavy\ rail} * (\%_{rail} * \%_{medium\text{-}heavy}) + ER_{medium\text{-}heavy\ ship} * (\%_{ship} * \%_{medium\text{-}heavy}) + ER_{heavy\text{-}heavy\ rail} * (\%_{rail} * \%_{heavy\text{-}heavy}) + ER_{heavy\text{-}heavy\ ship} * (\%_{ship} * \%_{heavy\text{-}heavy})$

ER = 12 g/hr * (40% * 64.1%) + 15 g/hr * (60% * 64.1%) + 20 g/hr * (40% * 35.9%) + 22 g/hr * (60% * 35.9%)

ER = 3.08 g/hr + 5.77 g/hr + 2.87 g/hr + 4.74 g/hr

=16.5 g/hr

It must be noted that these calculations assume that vehicle activity within each activity classification remains sufficiently similar to that used to develop the original driving cycles. It is not possible to examine the emissions or fuel consumption based on a change in the ratio of medium-heavy to heavy-heavy activity as the ratio in use (~64% medium-heavy and ~36% heavy-heavy) arose from analysis of the data and not as an estimate.