URS/HMM/Arup Joint Venture

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MEMORANDUM

To: **PMT**
From: Nathalia Prasetyo Jo (URS)
Date: July 12, 2010
Subject: **Wind-Generated Fugitive Dust Emissions from a Passing High-Speed Train**

Wind erosion occurs when drag forces or shear stresses exerted by the wind exceed the retention forces acting on particles or debris at the surface. Once the minimum wind speed required to initiate particle motion (threshold friction velocity) has been reached, wind erosion occurs as a function of wind power or wind speed.

Trains traveling at high velocity, such as the High-Speed Train, drag the surrounding air along the side of its body, which induces sideways turbulent fluctuations and rear wake. The strong turbulent airflow along the sides of a moving train and the wake at the rear of the train may resuspend erodible debris and fine particulates from the surface of the surrounding impacted area, similar to particle resuspension from wind erosion.

Methodology

To estimate the fugitive dust emission from the particle resuspension, the AP42 guidance Chapter 13.2.5 Wind Erosion was used to quantify the emission factor for wind-generated fugitive particulates emissions from a passing High-Speed Train. This memo presents the approach used to estimate the annual PM_{10} and $PM_{2.5}$ emissions from the High-Speed Train operation based on the AP42 guidance and current project description (at 15%design).

Annual wind-generated fugitive dust/particulates emissions from a passing High-Speed Train are a function of the impacted zone area and the wind erosion emission factor (per unit area). According to the AP42 guidance, the wind erosion emission factor emission factor (in terms of mass per unit area) is a function of the disturbance frequency (where disturbance is defined as an action that results in the exposure of fresh surface material) in a year and erosion potential (which depends on friction velocity and threshold friction velocity).

The influencing factors such as the impacted zone area, wind erosion emission factor, disturbance frequency, erosion potential and induced wind speed profile are discussed in detail in the following subsections.

Impacted Zone Area

The impacted zone area for the High-Speed Train scenario is defined as the surface area within both shoulders of the train track or within the right of way, at which the maximum friction velocity on the surface material is higher than the threshold friction velocity (the minimum wind speed required to initiate particle motion).

The length of the impacted zone area is equal to the length of the at-grade track. Along the Fresno to Bakersfield alignment, the length of the at-grade track is approximately 43.56 miles (total track length subtracted by the elevated track section length)[1].

The width of the impacted zone is twice the distance from the beginning of the right of way area to the point where the corresponding maximum surface friction velocity generated by the induced turbulence is equal to the threshold friction velocity (assumed 0.19 m/s, based on the lowest value available for disturbed desert soil[2]). In this memo, the width of the impacted zone is referred to in terms of distance from the train body. The doubling of width was to account for the right of way area on the left and right side of the train track.

The boundary for the impacted zone is assumed to start at beginning of the right of way area (approximately one meter from the train body) and end at the distance where the corresponding friction velocity is equal to the threshold friction velocity. The surface area from the train body to the beginning of the right of way area was assumed to consist of non-erodible material because that area is within the embankment and rock ballast area.

To quantify the fugitive dust emissions generated by a High-Speed train passing at the speed of 220 mph, the emission factor needs to account for the induced wind speed profile and the distance within the impacted zone. Further discussion on the determination of the impacted zone boundary is presented in the induced wind speed section.

Wind Erosion Emission Factor

Based on the AP42 guidance, the emission factor for wind-generated dust emissions from the surface material of the impacted zone should be calculated as follows:

Emission factor (g/m2): $k\sum_{i=1}^{N} P_i$ (Eq.1)

Where:

k = particle size multiplier
N = number of disturbances per year
Pi = erosion potential corresponding to the observed (or probable) fastest mile of wind for the ith period between disturbances, g/m^2

As described in Eq.1, the emission factor is a function of the disturbance frequency and erosion potential. The approach and assumptions used to determine the disturbance frequency and

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1 The length of at-grade track was estimated based on the Fresno to Bakersfield HST Alignments Preliminary Draft Map, URS, 2010.

2 Watson, J.G, "Effectiveness Demonstration of Fugitive Dust Control Methods for Public Unpaved Roads and Unpaved Shoulders on Paved Roads", DRI Document No. 685-5200. IF2: August 2, 1996.

erosion potential for the High-Speed Train operation scenario are presented as follows:

Disturbance Frequency

The disturbance is defined as an action that results in the exposure of fresh surface material. The number of disturbances per year during normal High-Speed Train operation is equal to the frequency of right of way access in a year (for maintenance or other purposes). The wind generated emission factor is dependent on the disturbance frequency because each time that the right of way surface area is disturbed, its erosion potential is restored.

The right of way surface area is currently expected to be disturbed twice monthly for visual inspection based on the operational and maintenance schedule of the High-Speed Train. Therefore, the erosion potential is assumed to be restored twice a month, which translates to 24 disturbances/year or N=24[3].

Erosion Potential

The erosion potential (P_i) is the finite availability of erodible material (mass/area) on a surface. For the wind erosion emission factor calculation, P_i is defined as the erosion potential corresponding to the observed fastest mile of wind[4] for the ith period between disturbances, and can be calculated as follows:

$$P = 58\,(u^* - u^*_t)^2 + 25\,(u^* - u^*_t) \qquad \text{(Eq.2)}$$

$$P = 0 \text{ for } u^* < u^*_t \qquad \text{(Eq.3)}$$

Where:

u^* = friction velocity (m/s)

u^*_t = threshold friction velocity (m/s). Assumed 0.19 m/s, based on the lowest value available for disturbed desert soil.

Since there was no documentation for the friction velocity from High-Speed Train operation, induced wind velocity was used to estimate the friction velocity on the right of way surface based on the correlation given by Eq.4.

$$u_z = \frac{u^*}{0.4}\ln\left(\frac{z}{z_0}\right) \qquad (z > z_0) \qquad \text{(Eq.4)}$$

Where:

u_z = induced wind speed, m/s

u^* = friction velocity, m/s

z = height above test surface, cm

z_0 = roughness height, cm

0.4 = von Karman's constant, dimensionless

3 Email correspondence between Thomas Baily (URS) with Arnold Luft (ARUP) dated July 6, 2010.

4 Fastest mile is the fastest one minute observed wind speed taken from a multiple register that contains a time record of the passing of each mile of wind

By substituting the friction velocity (u*) from Eq.4 into Eq.2 and the erosion potential (Pi) from Eq. 2 into Eq. 1, the emission factor in Eq.1 can be expressed as a function of induced wind speed as shown in Eq. 5

$$\text{Emission factor (g/m}^2\text{): } k\sum_{i=1}^{N}\left[58\left(\frac{0.4\,u_z}{\ln\left(\frac{z}{z_0}\right)} - u_t^*\right)^2 + 25\left(\frac{0.4\,u_z}{\ln\left(\frac{z}{z_0}\right)} - u_t^*\right)\right]_i \qquad \text{(Eq.5)}$$

Where:
k = particle size multiplier (0.5 for PM_{10} and 0.075 for $PM_{2.5}$).
u_z = induced wind speed at a certain height above the surface (m/s). Note that emissions are only calculated in area with $u^* > u^*_t$. Because, when $u^* < u^*_t$, the erosion potential (P) is equal to zero.
u^*_t = threshold friction velocity. Assumed 0.19 m/s, based on the lowest value available for disturbed desert soil.
z = height above the surface (288 cm), based on 1/2 of the train height (1.88 m) and the average embankment height (3ft ~1 meter) with respect to the right of way5.
z_0 = surface roughness height (cm), assume 0.01 cm for the at grade right of way
0.4 = von Karman's constant, dimensionless

By substituting the assumptions above and other known parameters into Eq. 5, the equation can be simplified to.

$$\text{Emission factor (g/m}^2\text{): } k\sum_{i=1}^{N}\left[58\,(0.038955u_z - 0.19)^2 + 25\,(0.038955u_z - 0.19)\right]_i \text{ (Eq.6)}$$

Where:
k = particle size multiplier (0.5 for PM_{10} and 0.075 for $PM_{2.5}$).
u_z = induced wind speed at a certain height above the surface (m/s). Note that emissions are only calculated in area with $u_z > 4.88$ m/s (a substitute for $u^* > u^*_t$). Because, when $u^* < u^*_t$, the erosion potential (P) is equal to zero.

As shown in Eq. 6, the emission factor can be expressed as a function of induced wind speed along the side of the train body. By integrating the emission factor function in Eq.6 across the induced wind speed values within the impacted zone boundary (u_z) area, and multiplying the emission factor by the number of disturbance (24 times per year) and the particle size multiplier (k), the annual fugitive dust emissions from the High-Speed Train activity can be estimated. Dust emissions generated by the wake at the rear of the train were not added to this calculation to avoid double counting. The erodible dust is already suspended in the air when the rear end of the train passes through and therefore additional turbulence or the rear wake will not contribute to more raised dust in the air.

Induced Wind Speed Profile

The width of the impacted zone is twice the distance from the beginning of the right of way to

5 Track related measurements are based on Technical Memorandum, Typical Cross Sections for 15% Design TM 1.1.21 Appendix A: Two Track At-Grade Drawing and Project Description Summary (June 28, 2010)

the point where the corresponding maximum surface friction velocity generated by the induced turbulence is equal to the threshold friction velocity. To determine the distance where the corresponding maximum surface friction velocity generated by the induced turbulence is equal to the threshold friction velocity, a wind speed profile analysis is required.

A study on the potential aerodynamic forces created by a passing High-Speed Train on nearby objects (such as humans standing in the proximity of the train) are influenced by train speed, distance from the train, and the geometry of the train[6]. Li, et. al. analyzed the maximum wind velocity around a human body for a specific train speed as a function of human-train distance based on different train shape models:

$$u = (1.2319)^{0.072v-4} \times (0.4575d^2 - 3.5496d + 9.1545) \qquad \text{(Eq.7)}$$

Where:

u: the maximum wind velocity around human body near the train (m/s).
d: human-train distance (m).
v: train running speed (m/s).

The range of train speeds specified for Eq. 7 are between 55.56 m/s and 97.22 m/s (between 124 mph and 217 mph) with a human-train distance between 1.0 m and 3.5 m. This raises questions about the validity of this equation to estimate aerodynamic forces from a High Speed train traveling at a speed of 220 mph.

An induced wind speed profile comparison was graphed to determine the relative accuracy of using Eq 7 to estimated aerodynamic forces for train speeds of 220 mp compared to 217 mph (the upper bound of the train speed range for Eq 7). Figure 1 shows that Eq. 7 presents a similar trend when a train speed of 220 mph is used as compared to a train speed of 217 mph. Therefore Eq. 7 can be used to determine the induced wind speed profile as a function of distance from train body for train passing at 220 mph.

6 Li, Renxian, et.al, "A Study of the Influence of Aerodynamic Forces on a Human Body near a High-Speed Train, Aerodynamics of Heavy Vehicles", Trucks, Buses, and Trains, 2008.

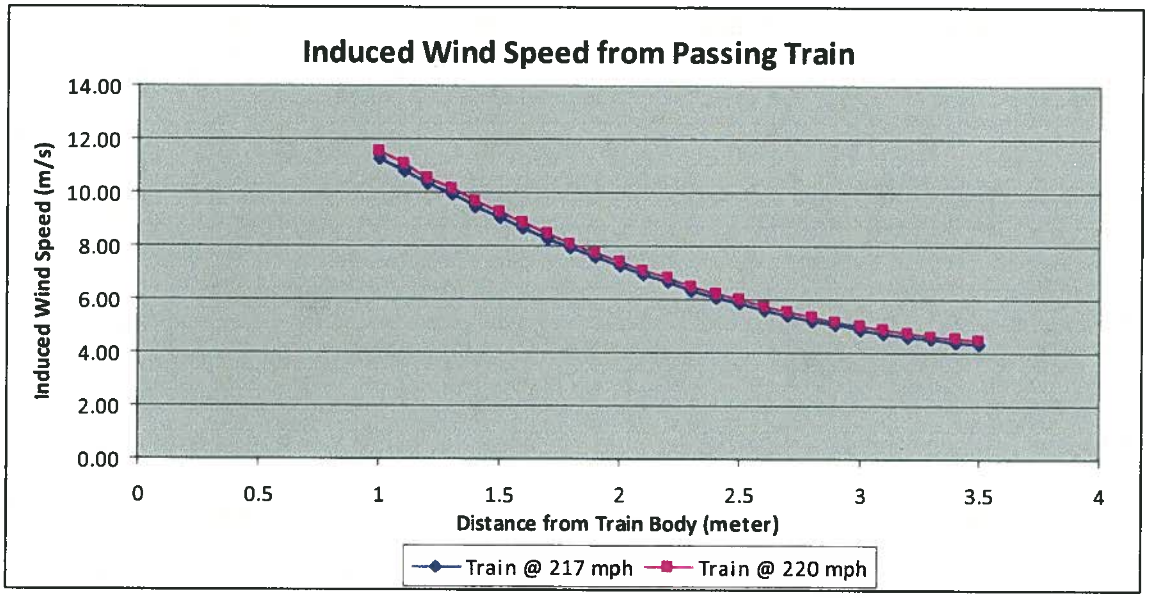

Figure 1. Wind Speed Profile Comparison from Train at 220 mph and 217 mph

Emission Calculation

The emission factor profiles over the distance from the train body are presented in Figure 2 and the emission factor over the impacted zone area is summarized in Table 1.

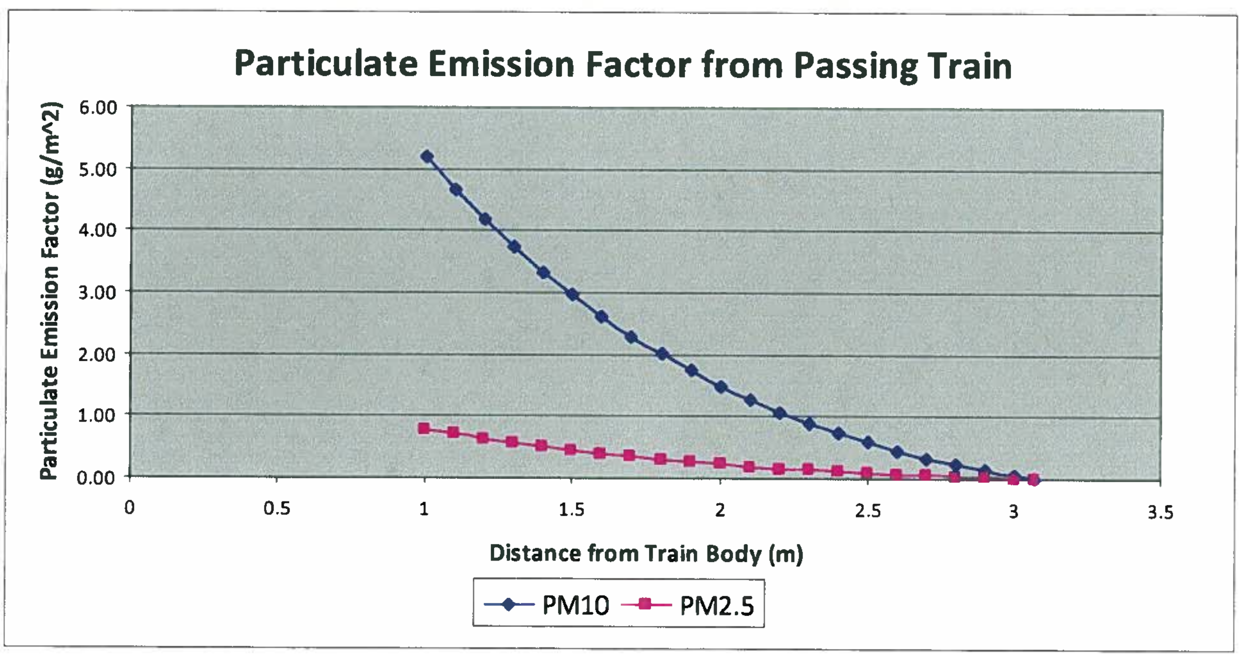

Figure 2. Particulate Emission Factor from Passing Train

Table 1. Emission Factor from Passing Train

Distance from Train-Body	Wind Speed (220 mph Train)	Friction Velocity	Erosion Potential	Emission Factor (g/m^2)	
(m)	u (m/s)	u*(m/s)	P (g/m^2)	PM_{10}	$PM_{2.5}$
1	11.53	0.45	10.37	5.18	0.78
1.1	11.03	0.43	9.33	4.67	0.70
1.2	10.56	0.41	8.38	4.19	0.63
1.3	10.10	0.39	7.49	3.75	0.56
1.4	9.66	0.38	6.68	3.34	0.50
1.5	9.24	0.36	5.92	2.96	0.44
1.6	8.83	0.34	5.23	2.62	0.39
1.7	8.45	0.33	4.60	2.30	0.34
1.8	8.08	0.31	4.02	2.01	0.30
1.9	7.72	0.30	3.48	1.74	0.26
2	7.39	0.29	3.00	1.50	0.22
2.1	7.07	0.28	2.56	1.28	0.19
2.2	6.77	0.26	2.16	1.08	0.16
2.3	6.48	0.25	1.79	0.90	0.13
2.4	6.22	0.24	1.46	0.73	0.11
2.5	5.97	0.23	1.17	0.58	0.09
2.6	5.74	0.22	0.90	0.45	0.07
2.7	5.53	0.22	0.67	0.33	0.05
2.8	5.33	0.21	0.46	0.23	0.03
2.9	5.15	0.20	0.27	0.14	0.02
3	4.99	0.19	0.11	0.05	0.01
3.07	4.88	0.19	0.01	0.00	0.00

As shown in Table 1, the corresponding friction velocity at the distance of 3.07 meters from the train body is equal to the threshold friction velocity of 0.19 m/s. Therefore, emission factor for wind-generated dust emissions should be calculated from the beginning of the right of way (1 meter from the train body) to the distance of 3.07 meters from the train body.

The emission factor for wind-generated particulate emissions from a passing High-Speed Train moving at 220 mph was calculated with the following steps:

- Using Eq. 6 and Eq. 7, integrate the emission factor over the distance of 1 meter to 3.07 meter from the train body.
- Multiply by particle size multiplier, k (0.5 for PM_{10} and 0.075 for $PM_{2.5}$)
- Multiply by 43.56 miles of at grade track length (impacted zone length).
- Multiply by two (to account for the left and right shoulders).
- Multiply by 24 disturbances per year (twice monthly).

Using the trapezoidal rule for numerical integration, the results for emission factor for wind-generated particulate emissions from a passing High-Speed train moving at 220 mph are 26.53 lb PM_{10} /miles of at grade track and 3.98 lb $PM_{2.5}$/ miles of at grade track. Multiplied by the impacted zone length and disturbance frequency, the annual PM_{10} and $PM_{2.5}$ emissions from the High-Speed Train operation for the Fresno-Bakersfield section are 13.9 ton of PM_{10} /year and 2.1 ton of $PM_{2.5}$ /year.

Reference

H. Lee, "Assessment of Potential Aerodynamic Effects on Personnel and Equipment in Proximity to High-Speed Trains Operations", DOT/FRA/ORD-99/11, December 1999.

U.S. Environmental Protection Agency (USEPA), "Compilation of Air Pollutant Emission Factors Chapter 13.2.5", AP-42, 5th ed., Washington, D. C., 2006.

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