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ECONOMIC HAUL RADIUS AS AFFECTED BY DIESEL FUEL COST

By Andrew Reynolds, Yashasvi Raj, and Douglas D. Gransberg, PE, PhD.

ABSTRACT

The cost of diesel fuel has remained both consistently high and volatile, and the equipment – intensive construction industry has experienced increasing uncertainty in transportation costs Therefore, this study evaluates the impact of diesel cost volatility on the economic distance for hauling aggregates. The paper proposes the calculation of an economic haul radius to quantify hauling costs over a probabilistic range in diesel prices and thereby quantify the impact. The literature defines the economic haul distance as the point where the cost of hauling the material equals the supplier cost of the material at the source. The paper uses the Puerifoy method to determine operation costs for a typical aggregate haul truck and from that output to determine the economic haul radius. The paper finds that the economic distance that aggregate can be hauled is a direct function of the price of diesel fuel used in the contractor's bid. It recommends that the resulting stochastic algorithm can be used to estimate economic haul distances for construction projects that uses large amounts of aggregate.

INTRODUCTION

Aggregate is used extensively in all forms of heavy construction and is a primary component in structural and paving concretes, subgrades and temporary or permanent roadways. To be used in these applications, the aggregate must be of a sufficient quality and possess certain qualities necessary for the given application. Conventional wisdom holds that aggregate will be hauled from the nearest acceptable source to minimize transportation costs and maximize productivity *(1)*. In some parts of the country, quality sources of aggregate have become scarce, both because of depletion from past use and because of the development of stricter specifications aggregate properties research *(2)*. The fear is that as the availability of quality aggregate declines the distance over which it must be hauled will increase, further increasing its cost. If the cost reaches a point where it is not economical, engineers may be forced to accept marginal aggregates that will potentially decrease the service life of the facility in which they are used.

Over the past two decades, the price of diesel fuel has increased by 360% *(3)* and sources of good aggregate have become more limited. The combined effect of these two causes is that the cost of aggregate intensive projects have increased substantially. Methods for planning future projects need to be improved to account for this trend, and cost estimates for projects must include consideration of likely aggregate haul distances, rather making the increasingly erroneous assumption that current bid tabulation prices will suffice. To address these issues, this paper proposes an algorithm to stochastically account for diesel price volatility in early project estimates to permit designers to assess the quality of aggregate sources within economic hauling distances and make informed design decisions with respect to local project conditions.

BACKGROUND

Diesel fuel prices vary over time. The overall trend is that price is increasing, but from year to year or month to month prices may increase, decrease or remain the same. Figure 1 shows that from 2010-2014, the average national monthly fuel price has increased by more than 31%, but year to year, the change has varied from +28.6% to -.75% *(3)*. Inconsistency in fuel price variation leads to uncertainty in hauling costs, especially in a competitive bid market where work must be done over a period of several construction seasons. Uncertainty in price leads to larger contingencies applied by contractors and higher unit prices which may push bids for a project over the expected budget.

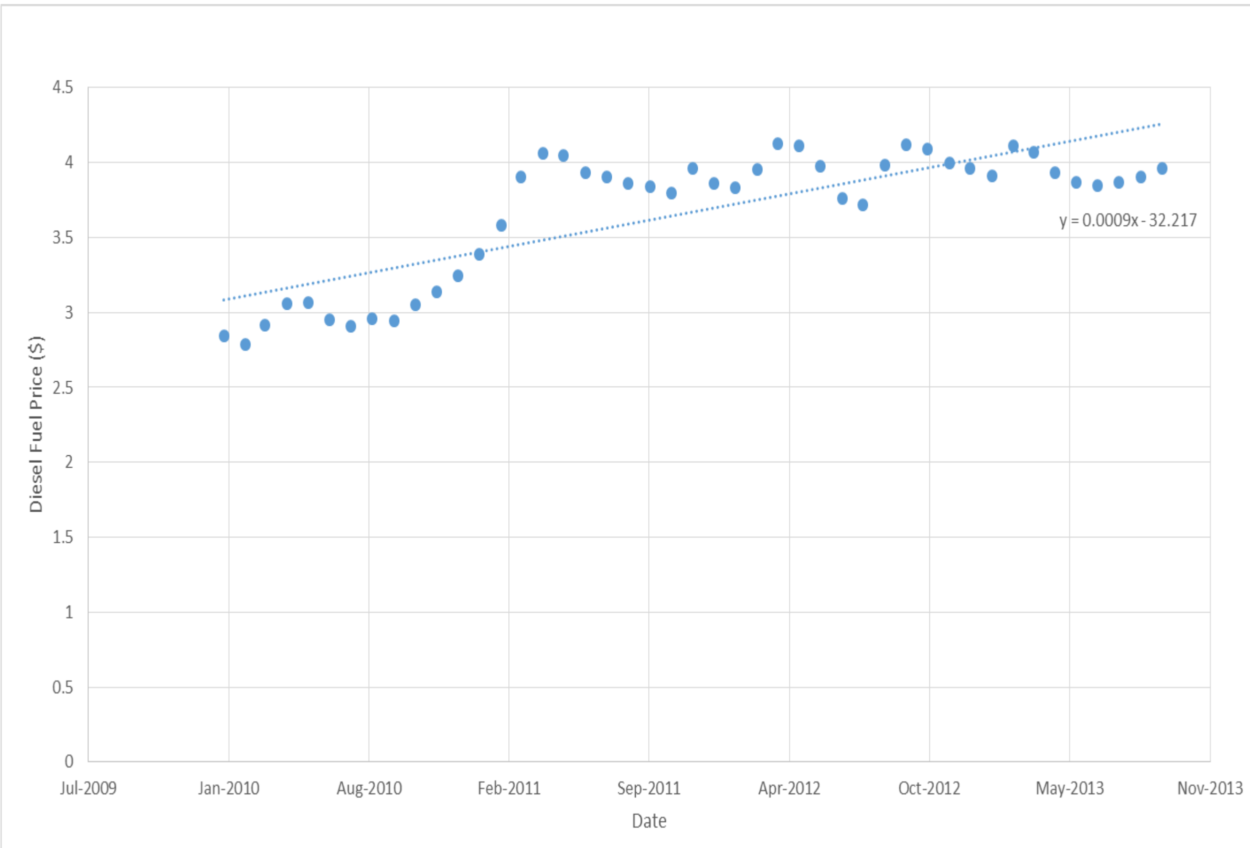

FIGURE 1 Variation in fuel prices from Jan 2010 to Sep 2013.

Figure 2 shows the change in diesel prices for the 12-month period ending in September 2013. It can be seen that there was a downward trend but since then prices have started to rise again. However, there is no simple method to predict where they will go in the next 12 months. Thus, since there appears to be a dip in pricing in the database, the potential that a given project's estimate will be lower than market conditions on bid day is high. While there is no easy resolution, moving the estimate from a deterministic model to a stochastic model will permit the engineer to better gauge the potential impact.

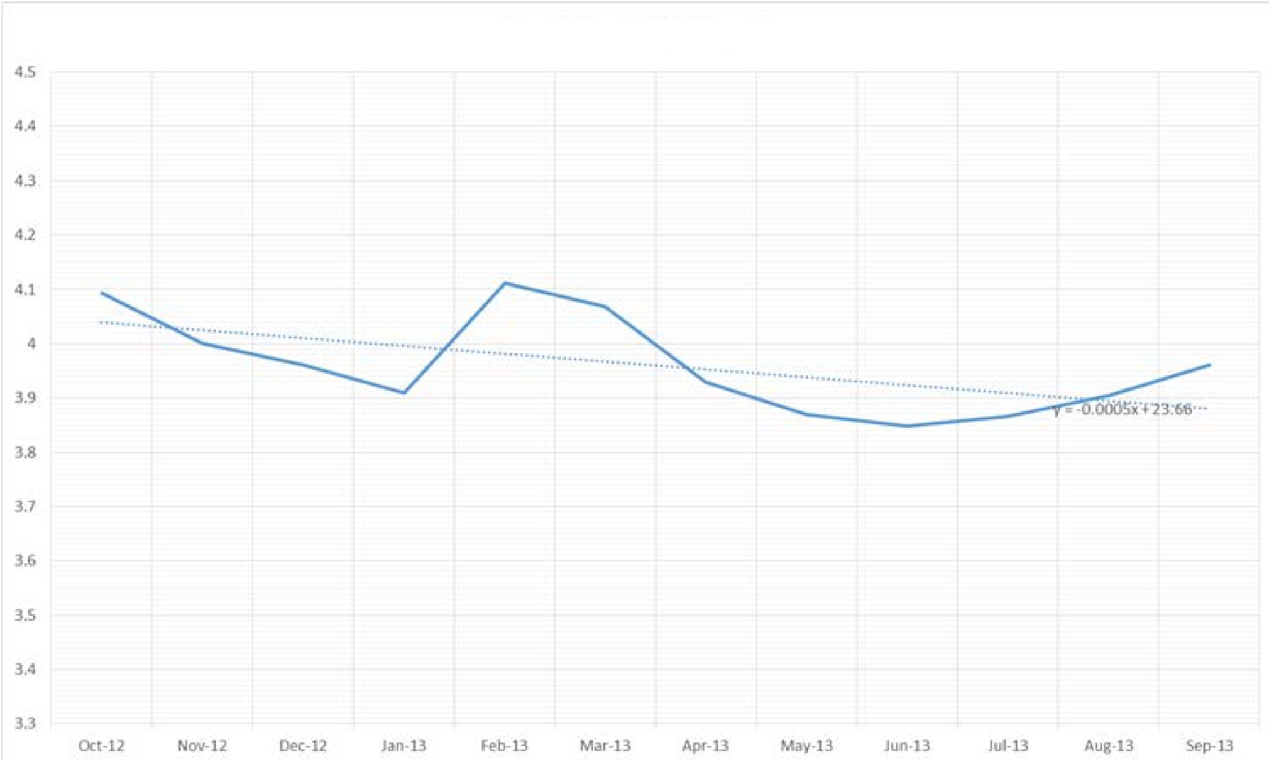

FIGURE 2 Variation in Diesel fuel prices from Oct 2012 to Sep 2013.

RAMIFICATIONS OF ECONOMIC HAUL RADIUS

Intuitively, as the cost of the fuel used to transport aggregate increases, the cost of hauling the aggregate should also increase. As haul costs increase the distance aggregate can be economically transported decreases. This in turn limit the number of accessible sources to those within the economic range of the intended project site. Although diesel fuel is a significant portion of the cost of aggregate production, the exclusion of road-use taxes and economy of bulk fuel purchases for use at a quarry site as well as the presence of electrical aggregate processing equipment, help to offset variations in base fuel price that cause larger fluctuations in on-road fuel cost.

The effect of a decreasing or increasing haul radius on a project can be significant. If a project's primary material is aggregate that must be hauled, then it is likely that the single largest cost component for that project will be the cost of providing the aggregate. If the material source is within economic hauling range, then the price of the material will be competitively reasonable, but if the haul radius larger than economic range, then the cost of the haul alone will be greater than the original cost of the material. History has shown that it does not take much of a variation in fuel cost to create a large project cost increase *(4)*.

DETERMINISTIC VERSUS STOCHASTIC BID ANALYSIS AND THE ABILITY TO COMPUTE THE LEVEL OF CONFIDENCE

Fuel price, and a resulting haul price have been traditionally viewed as a deterministic system, which is linked to an underlying and unchanging set of input values *(5)*. This leads to fuel cost being determined by recent fuel prices being fit to a straight line trend and used to determine a likely average fuel price in the future based on this trend. Recently, the industry has been moving toward the use of risk-based estimating. The change in methodology permits a level of confidence to be associated with the estimate as fuel price is evaluated probabilistically. This change allows variations within the present and projected time period to be taken into consideration when calculating a probable future cost. Another benefit of using a probabilistic approach is that a level of certainty can be determined from the statistical model. Both of these results allow for a more accurate estimate of an unknown future value, resulting in the development of a rational contingency and an estimate that will more closely conform to contractors' bids *(6)*.

METHODOLOGY

The methodology revolves around the development of a deterministic cost model for vehicle ownership and operating costs and then making the fuel cost probabilistic. A standard Monte Carlo simulation using commercial software is then run to determine the probability density function for the vehicle operating cost. This is then used to develop an economic haul radius based on the premise that the economic haul distance is the distance at which the cost of hauling the aggregate is equal to the cost of the material itself at the supplier.

The fuel price probability distribution was determined from the national average fuel prices published on the Energy Information Agency website (10/14/2013). These were input into commercial curve fitting software and the goodness of fit was determined by the least Chi-square approach *(7)*. Figure 3 shows the resulting distribution curve. This process was repeated for all other input variables to the vehicle operating cost model.

The Puerifoy method *(8)* of calculating vehicle ownership and operating cost was selected as the basis for the cost model. While there are a number of other common methods, such as the AGC method and the Corps of Engineers *(9)*. Puerifoy is the most well-known and is focused on the physics of the hauling operation. The primary input is the horsepower of the vehicle's engine which then drives the other inputs such as fuel costs, making it ideal for this particular analysis. This method has been used extensively in industry and evaluates all the major components of operating a given vehicle or piece of equipment. Other important features of the Puerifoy method are that it recognizes the time-value of money, includes maintenance and incidental costs and is easily adjustable to fit a given set of constraints.

A widely utilized and readily available truck model (Freightliner 122SD) was used for analysis and calculations. Capacity, engine output and maintenance quantities were determined from a prominent national manufacturer and other pertinent values obtained from literature or market sources. These values, along with the EIA average national fuel price obtained from were input into the Puerifoy equation and used to calculate the economic haul radius based on the price of a given material. The inputs used were generalized and may be higher or lower for individual cases depending on market conditions or location, but do represent a likely combination for an average operation and are a suitable basis for the model. Table 1shows the details of the calculations for the example aggregate truck.

TABLE 1 Puerifoy Method Example for a Severe Duty Dump Truck

Freightliner 122SD Quad Axle Dump Truck Equipment Horsepower: 505 Average conditions of use Estimated annual use in hours = 2000 hrs Total expected use in hours = 14,000 hrs Useful life = 14,000hrs / 2000 hrs/yr= 7 years	Tires Front and Drive = $4,600 Fuel cost = $3.95/gal Sales tax = included in item pricing “Factor” = Factor taken from the reference manual [12]
FACTORS FOR CALCULATIONS	
1. Interest = 5.00% Taxes, insurance & storage = 6.15% Salvage value = 30% Repair & Maintenance = 85% Depreciation cost Tire repair cost = 10% of straight-line depreciated tire cost Equipment under load 84% of the operating time Use 50-minute productive hour	
OWNERSHIP COST	
2. Initial cost = (List price – Tire cost) =($150,000-$4,600) = $145,400 Equivalent Uniform Annual Cost of IC = A_{IC} = IC[i(1+i)^n /[(1+i)^n -1]] $145,400 [0.1295(1+0.1295)^7 /[(1+0.1295)^7 -1]] = $32,825.36/yr Equivalent Uniform Annual Cost of SV = A_{SV} = SV[i/[(1+i)^n -1]] 0.30($145,400) [0.1295/[(1+0.1295)^7 -1]] = $4331.66/yr	
3.Hourly Ownership Cost = (A_{IC} – A_{SV})/Annual Use Hourly Ownership Cost = ($32,825.36/yr-$4331.66/yr)/2000 = Hourly Ownership Cost	=$ 14.25
OPERATING COST	
4. Fuel Cost = Combined Factor(consumption)(HP)(cost/gal) Equipment Load factor = 0.84 Time factor: 50 min/60min = 0.83 Equipment Combined factor = (0.83)(084) = 0.70 Equipment Fuel Cost = 0.70(.0285 gal/hr-hp)(505 hp)($3.95/gal)= Fuel Cost	$39.80/hr
Hourly Repair and Maintenance Cost = 0.85($7.17/hr)=$6.10 Maintenance Cost	$6.10
Tire Use cost = $4,600(A/F,12.95%,1.1)/2000hrs/yr=$2.38 Tire Repair cost = [$4,600/2200 hrs](0.10) = $0.21/hr Total Tire Cost	$2.59/hr
Lube Cost= [(HP)(Op.Factor)(Consumption)/(Gal/LB)+(volume/oil life)]*oil price Lube(lbs/hp/hr)=0.006	

Lube(gal/lb)=7.4 Oil change volume=11.375 gal Oil life=640 hrs Oil Price=$15/gal =[(505*0.70*0.006/7.4)+(11.375/640)]*$15 Lube Cost	$4.57/hr
12. *Total Hourly Operating Cost*	= $53.04
13. *Operators Hourly Wage (burden adjusted)*	= $ 28.25
14. **TOTAL OWNERSHIP & OPERATING COST**	= $95.54
SUMMARY	
Ownership Cost Per Hour	= $ 14.25
Operating Cost Per Hour	= $ 53.04
Operator Wage Per Hour	= $ 28.25
Total Cost Per Hour	= $ 95.54

Economic haul radius calculation

As previously stated, the economic haul distance is defined as the distance where the haul cost equals the material cost *(2)*.

Using a given haul ownership and operating cost, a resulting, and idealized haul radius can be determined by equation 1 below:

$$Cost\ to\ Haul = \frac{\$}{Hr} Operation \times \frac{Haul\ Distance}{Haul\ Speed} \quad \text{Eq. 1}$$

For economic haul:

$$Cost\ Haul = Cost\ Material \quad \text{Eq. 2}$$

Therefore:

$$Cost\ of\ Material = \frac{\$}{Hr} Operation \times \frac{Haul\ Distance}{Haul\ Speed} \quad \text{Eq. 3}$$

Rearranging:

$$Cost\ of\ Material = \frac{\$}{Hr} Operation \times \frac{Haul\ Distance}{Haul\ Speed} \quad \text{Eq. 4}$$

Because haul cost is assumed to account for a return trip to the point of origin, the haul distance is actual twice the haul radius yielding equation 5:

$$Haul\ Radius = \frac{1}{2} \times \frac{Cost\ of\ Material \times Haul\ Speed}{\$/_{Hr}\ Operation} \quad \text{Eq. 5}$$

Interpretation of the output

The model used for this output is generalized, and the resulting output should be viewed as such. Refining input values to better reflect a particular system could improve accuracy, but the base interaction between input values will remain. For example, various regions have different prevailing wage rates and changing this input value will change the economic haul radius as shown in Figure 3. However, Figure 3 is merely a snapshot at the national level. When the model is used for a specific project, the driver's cost will likely be deterministic as set for the prevailing wage agreement for the region.

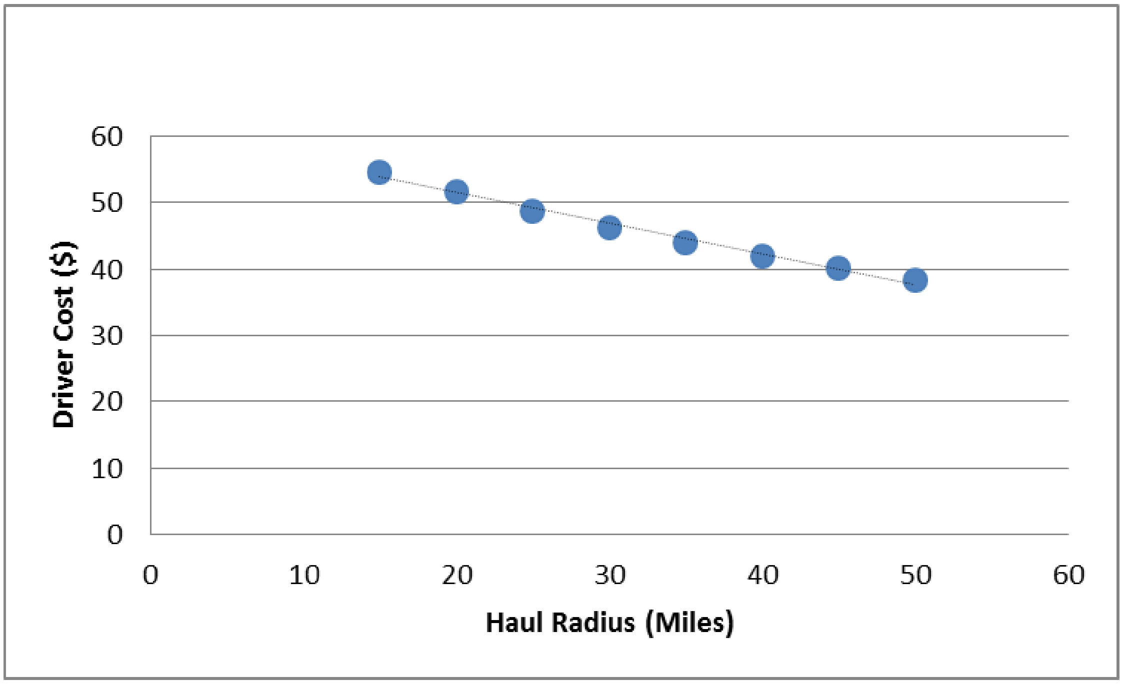

FIGURE 3 Driver cost Vs. Haul.

RESULTS

Fuel Prices

Stochastic models of national average diesel fuel price showed the most likely price to be $3.95 per gallon within a 90% confidence range of $3.82 to $4.14. Conservatively assuming that the general trend of fuel price is increasing for a typical engineer's estimate, the results of the model are shown in Figure 4 and illustrates how it permits a confidence level to be associated with a given distance, In this case, the estimator has a 95% certainty that the economic haul radius of material will not be greater than about 48 miles and therefore, the engineer must locate a suitable source of aggregate within the radius of the project site.

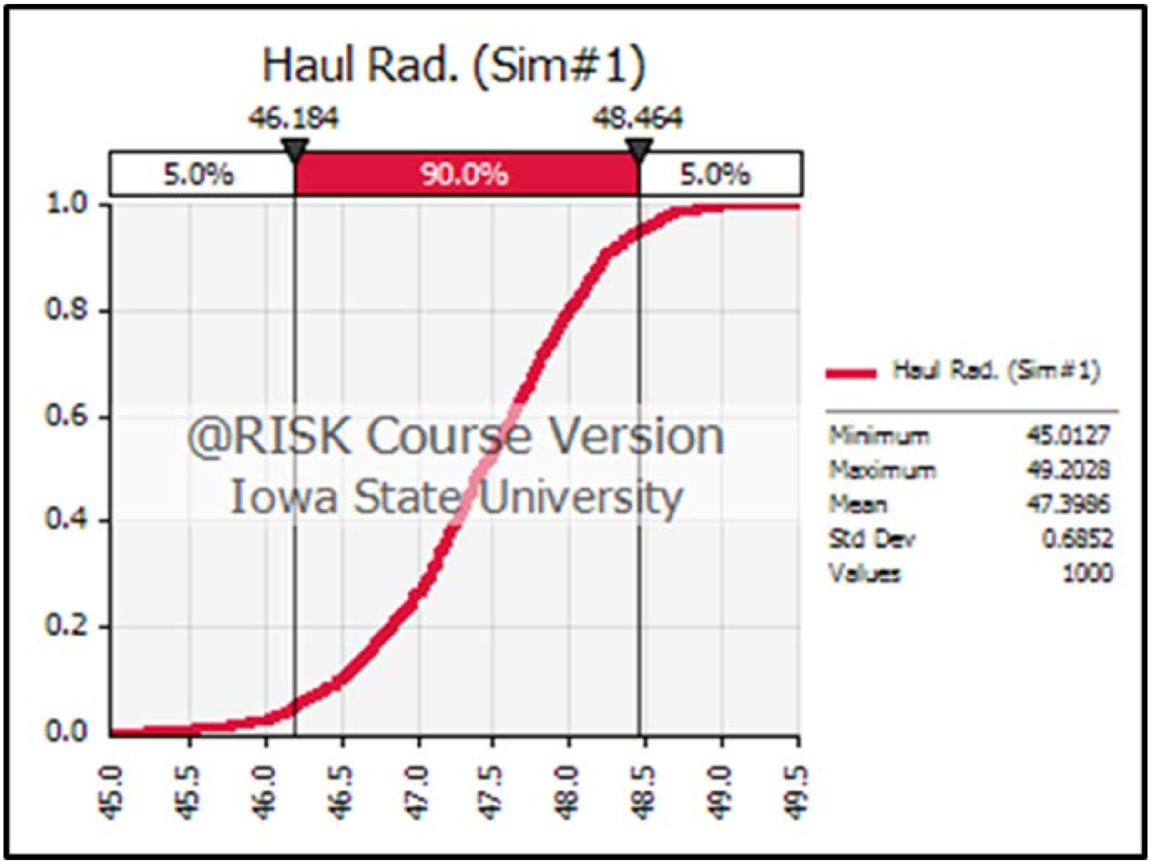

FIGURE 4 Cumulative probability function of economic haul radius.

From the stochastic inputs for the model, a tornado diagram can be created showing the sensitivity of each input value and the overall change of the model value. This is shown in Figure 5 and shows that the overall model is most sensitive to the fuel price, validating the underlying premise of this study. With the exception of lubricating oil price, the remainder of the inputs will be deterministic for a specific vehicle used on a specific project. Therefore, the model can be simplified if desired to use known values for interest, insurance, taxes, storage and fees, as well as average values for maintenance and tire repair. Lastly, Figure 6 shows the result if all inputs are deterministic except the fuel prices for the example truck.

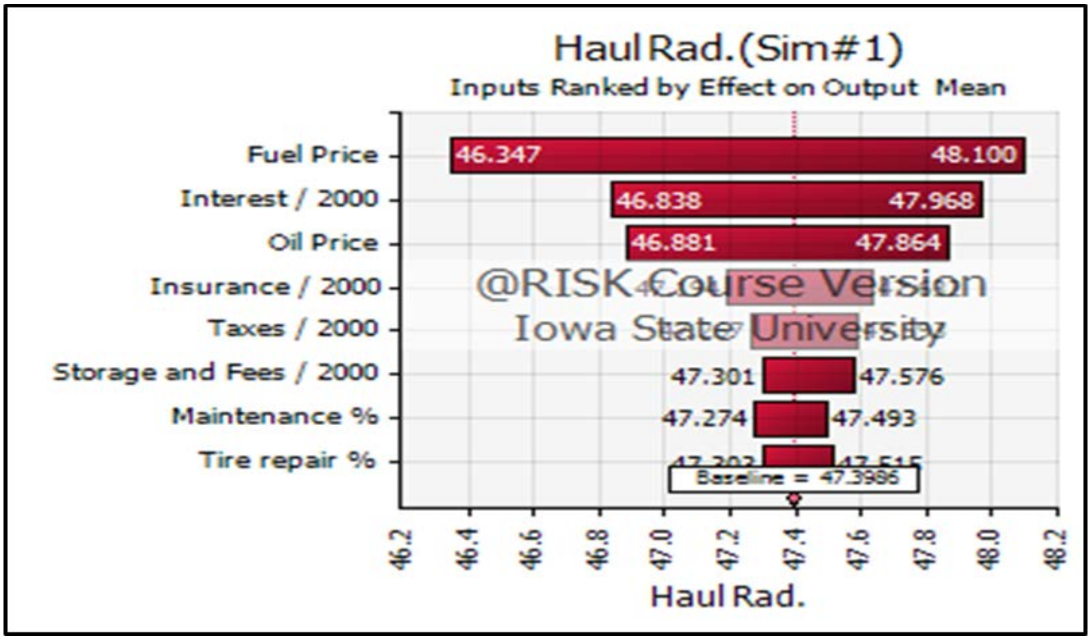

FIGURE 5 Tornado diagram for different stochastic inputs.

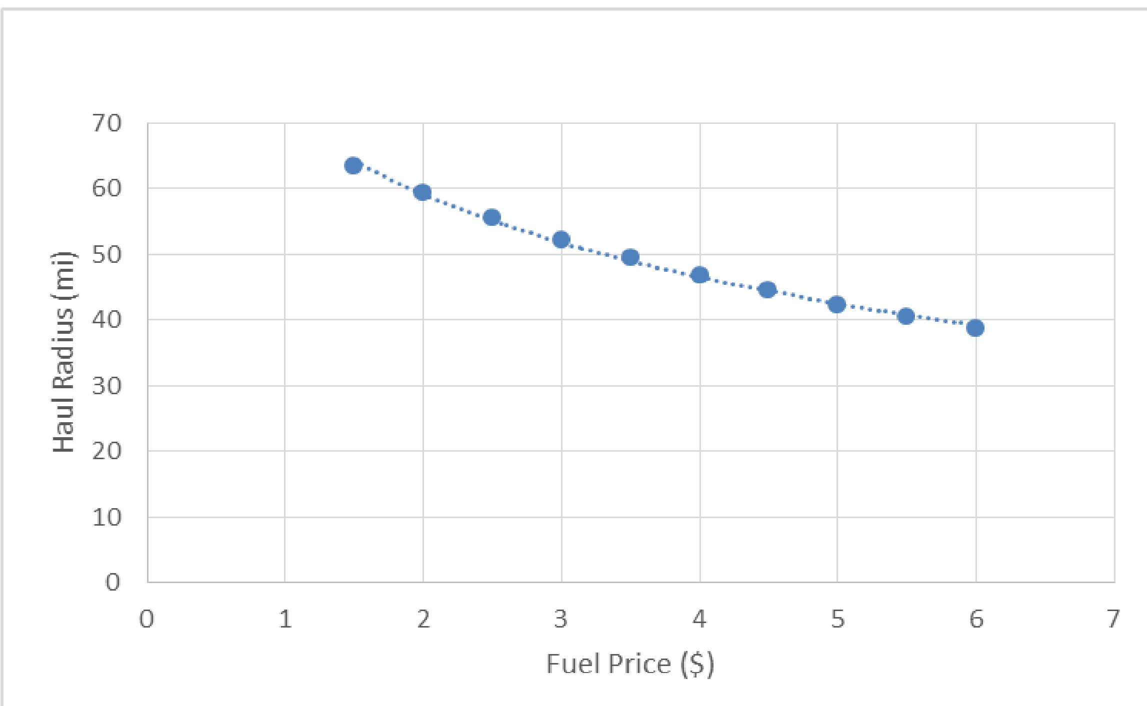

FIGURE 6 Fuel prices Vs. Economic haul radius. Note: $28.25/hour Driver (IOWA Zone 1-3 Davis-Bacon rate), $12.5/ton, 16 ton/load, 45 mph avg.

Interaction of Haul Speed and Fuel Pricing

The speed at which aggregate can be transported affects the transportation cost and hence the economic haul distance. This relationship is best shown by an example case. In central Iowa, sources of quality aggregate that meeting Iowa Department of Transportation specifications for polished stone value are limited to a few locations. For the Des Moines metro, almost all stone is obtained from a quarry in Ames, which is about twenty five miles north of the city. A project on the west side of the Des Moines metro would have to transport aggregate approximately 45 miles one-way. The most likely haul route falls primarily on Interstate Highway 35 where the trucks would be expected to average 55miles per hour (mph) Effective labor rates for heavy truck drivers are in the $25 range, and material price is $12.50/ton.

Given this information, and the model previously described above, the haul would remain economical until fuel prices hit about $7/gallon which is not likely for the foreseeable future. But, if the average haul speed drops 10 mph due to congestion or a construction work zone and fuel price was to approach $5/gallon, the haul would then be outside the limit of economic haul. Figure 7 shows the relationship between economic haul radius and average haul speed. For a location inside the metro, where haul speed is reduced to city speed limits, the effect of fuel price increases are that much more pronounced.

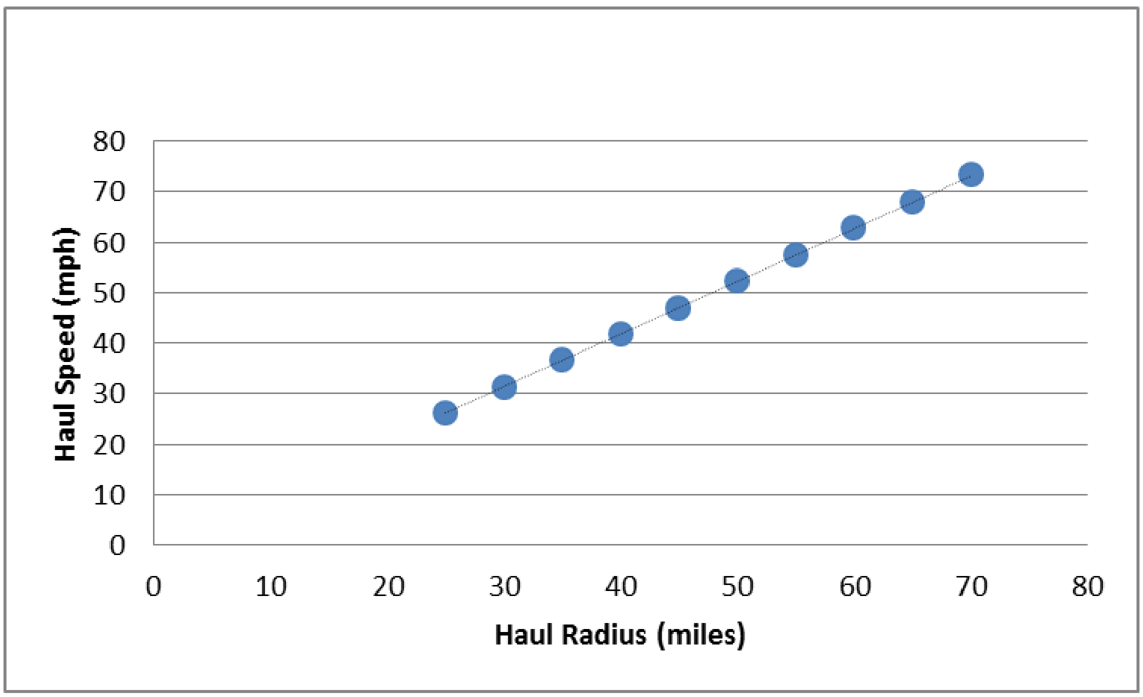

FIGURE 7 Haul speed Vs. Haul radius

The significance of this relationship is that even projects located reasonably near to material sources may become susceptible to cost overruns due to future fuel price increases. This issue is even more extreme if the project is located in a topographically complex or traffic heavy area where average haul speeds will be slow.

CONCLUSIONS AND RECOMMENDATIONS

The analysis described above demonstrates the utility of economic haul radius as a means of determining the impact of fuel price volatility for projects where large amounts of bulk material must be transported to the project site. This analysis should be conducted early in the project development process to identify sources of acceptable material and whether or not they are within an economic distance based on the volatility of fuel prices felt in the recent past. If the acceptable material source falls outside the economic haul radius to the project, the engineer should consider other design alternatives if any are available. If not, then a sufficient contingency must be allotted to the project budget to mitigate the risk of fuel price volatility. Economic haul distance is inversely proportional to diesel fuel pricing. In the paper's example cost model, the trend is about two miles of reduction per $0.25-per-gallon increase in price for a typical project in the Des Moines, Iowa metropolitan area. In areas that have higher labor costs or projects that require lower speed haul routes, the effect of fuel change will be somewhat suppressed, but the overall cost of haul will be relatively higher.

Stochastically modeling fuel prices provides a better understanding of the impact of fuel prices on a given job. Deterministic modeling of fuel price does not account for the possibility of a price higher than the value chosen. Stochastic modeling takes the probability that the price will be higher or lower and creates a range of price with a level of certainty and provides the most likely price based on that probability. Increasing fuel prices can decimate contractor's margins and contingencies and push owner costs well above those anticipated. Stochastically quantifying the fuel price escalation risk on a project provides value to both owners and constructors by permitting a rational contingency to be allocated to the risk.

As diesel prices go up, the probability that marginal aggregates will be used on the job goes up as well. As diesel prices continue to increase overtime, there will come a point where it is likely that most projects in poor quality aggregate areas will be over the limit of economic haul. This increases the likelihood that lower quality materials will be substituted as a cost saving measure or shear necessity to conduct the work. This will cause project life cycles to be shortened and, without a change of methodology, construction cost to continue to increase.

Given present market conditions and past experience with the volatility of fuel prices, it is likely that more aggregate-intensive projects will fall outside of the limit of economic haul and a premium will need to be paid to complete projects in that area by importing suitable aggregate from greater distances. This might force engineers to resolve this problem specifying lower quality aggregate reducing pavement durability and overall service life in exchange for an affordable cost.

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