Risk assessment of hazardous material transportation routes in the City of New Haven

FINAL REPORT

by

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INTRODUCTION

The City of New Haven, Connecticut is in the process of reclassifying and repurposing Route 34 (Figure 1), currently a six-lane divided highway stub running into downtown New Haven, to a pair of urban boulevards designed to promote multi-modal transportation, pedestrian activity, economic development and urban infill (http://downtowncrossingnewhaven.com/). Originally conceived as a connection to the Lower Naugatauk Valley, Route 34 drew a substantial amount of freight traffic, including hazardous material (HazMat) transport traffic from the Port of New Haven, southeast of downtown on I-95. A significant volume of HazMat (primarily petroleum products) travels from the port, traverses the Route 34 corridor and leaves New Haven toward the west on Route 34 toward Derby, CT.
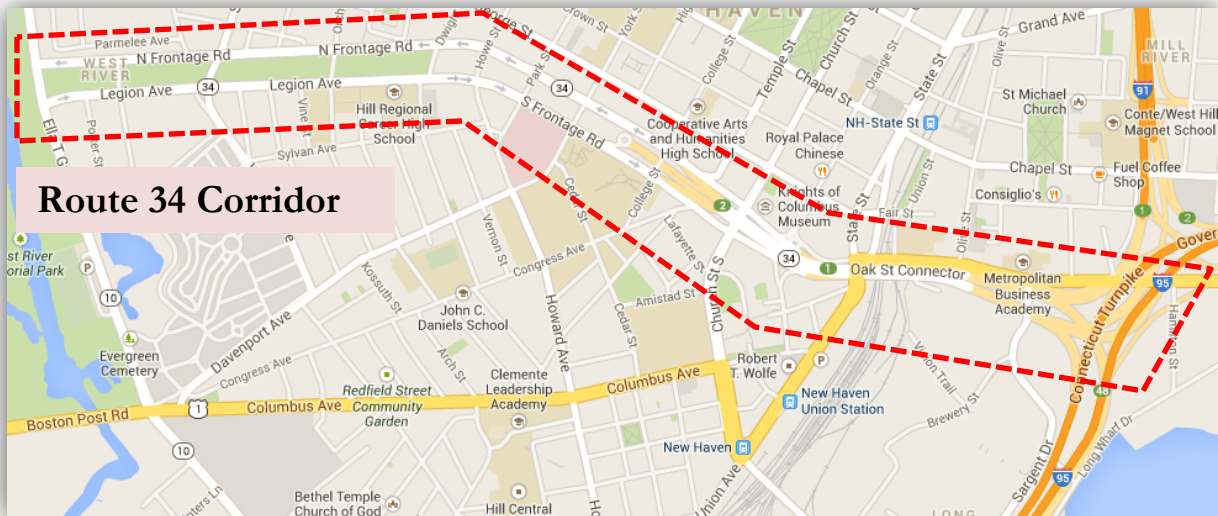

Figure 1: Map of Route 34 corridor and existing roadway layout

According to the 2007 Commdity Flow Survey (USDOT 2010), the shipment of HazMat by truck nationwide is increasing and in 2007 Connecticut saw over 18 million tons of HazMat transport throughout the state. Furthermore, New Haven serves as an important port for the distribution of fuel oil and other petroleum & coal products throughout New England (of which Connecticut saw over 150,000 tons in 2007) – making HazMat considerations important for transportation decisions.

A significant element of the freeway conversion to a downtown urban environment is the creation of an environment that is conducive to, and safe for, the movement and gathering of pedestrians and cyclists. Such an environment is envisioned to promote economic activity and the creation of places people enjoy. From both a safety and a perception perspective, these goals are seemingly at odds with heavy volumes of HazMat transport. The purpose of this study was to quantitatively investigate whether an alternative HazMat routing south of the current Route 34 along I-95 and Route 10 would be a safer alternative. The alternate route is depicted in Figure 2: it reroutes Route 34 HazMat traffic south along I-95, exiting at Exit 45, continuing northbound on Route 10 (Elle T. Grasso Blvd) until reconnecting with the original route leading west toward Derby.

There are three key elements of this problem that are strongly connected to risk characterization – these three elements drive the analysis presented in this report:

1. Identification of an appropriate spatial threshold for the risk associated with a HazMat release
2. Selecting appropriate units of risk measurement
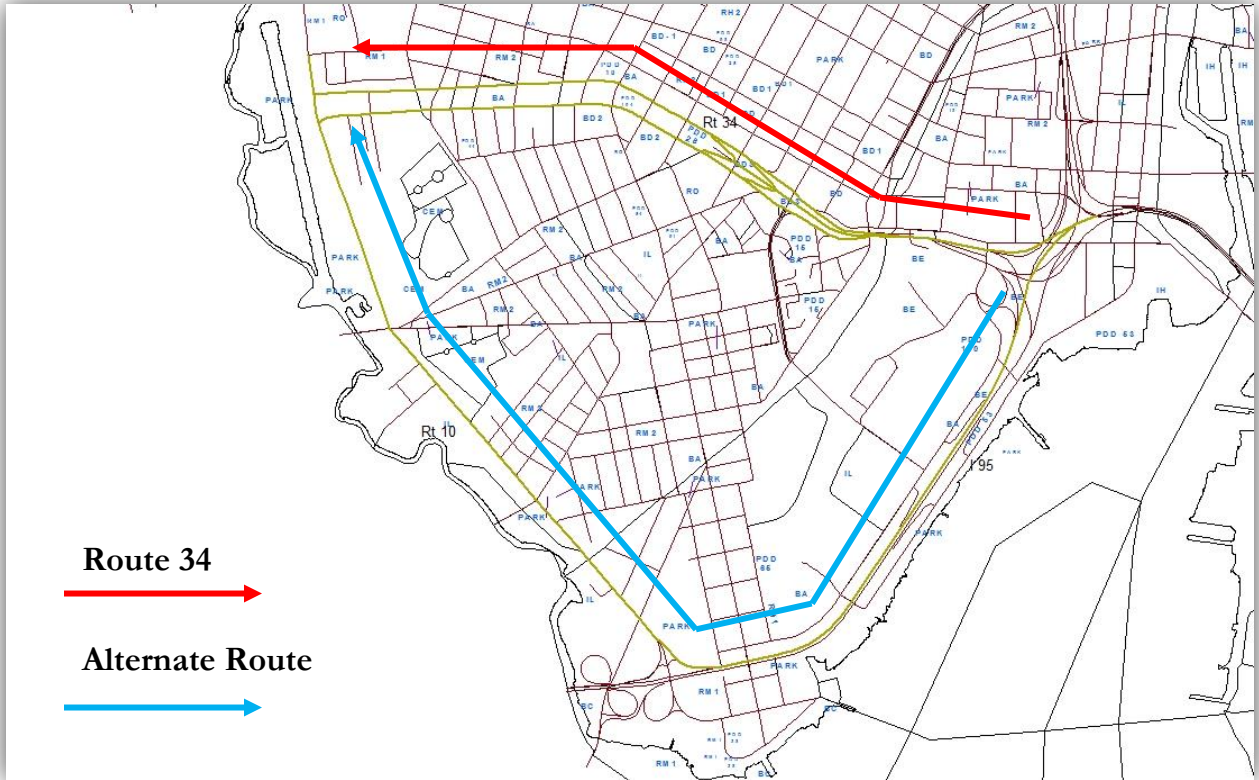3. Accommodating spatial variability in risk measurement.

Figure 2: HazMat paths to be considered for analysis

BACKGROUND

Transportation of HazMat poses risks because of the danger associated with the accidental release of hazardous materials. An incident involving a vehicle carrying hazardous materials cargo can produce undesirable short- and long-term consequences to human health and the environment, including severe illness, death, irreversible pollution, and in the worst case may require evacuation. A recent commodity survey of United States Department of Transportation reports that HazMat transportation on highways and railways has increased by approximately 4% and 16% from 2002 to 2007 respectively (USDOT 2010). Because of the huge volume of HazMat transportation and the negative consequences associated with HazMat incidents, various risk minimization procedures have been proposed.

Policies available to government agencies for HazMat transport risk management can both proactive and reactive (Marcotte et al. 2009). The latter group of policies aims at confining the undesirable consequences of a HazMat incident after the occurrence of an incident. In contrast, the proactive risk mitigation policies aim at reducing the likelihood and consequences of HazMat incident a priori, which is what this research is about. From the perspective of network modeling, effective methods in attack and disaster preparation are those that identify routes that will give lowest risk for HazMat flow.

The U.S Department of Transportation defines a hazardous materials (or dangerous goods) as a substance or material that the Secretary of Transportation has determined is capable of posing an unreasonable risk to health, safety, and property when transported in commerce, and has designated as hazardous under section 5103 of the Federal Hazardous Materials Transportation law (49 U.S.C. 5103) (PHMSA 2008). The department of transportation categorizes hazardous materials into nine classes: explosive, gases, flammable liquids, flammable solids, oxidizers and organic peroxides, toxic materials and infectious substance, radioactive materials, corrosive materials, and miscellaneous dangerous goods. Any vehicle carrying these materials above a certain amount must show placard on the vehicle. Hazardous materials transportation is often considered as low probability high consequence (Sherali et al. 1997) because of the severe consequences associated with each accidental release.

Hazardous material routing differs from conventional vehicle routing because of the additional consequences that can result when HazMat transport vehicles are involved in accidents. Erkut et al. (2007) has provided a comprehensive concept of modeling risk for hazardous materials. Due to the complexity of enumerating all possible forms of loss and the fact that consequences are proportional to the population in the neighborhood of the incident, population exposure (PE) is almost always taken as the surrogate measure of consequence.

$$PE(r) = \sum_{i \epsilon r} C_i$$

Where $PE(r)$ is the population exposure of route r, C_i is the neighboring population on link, and r is the set of available routes. In the Federal Highway Administration guidelines for hazardous materials population exposure has been viewed as the most important criterion in routing HazMat (USDOT 1996).

Routing of hazardous materials shipment involves selection among alternative paths between origins – destination pairs. Several approaches to HazMat routing that have been reported in the literature involving various network modeling and routing techniques. These techniques are beyond the scope of this report, Rahman and Lownes (in review) provide a complete review.

The federal hazardous materials transportation act (Section 5112 of Title 49) states that for highway routing of HazMat a state shall consider various variables such as population densities, emergency response capabilities, effect on commerce, and delays. DOT has prepared a highway routing guides for non-radioactive hazardous materials. The routing criterion described in the guide (USDOT 1996) states that if the ratio of the relative risk of the current routing to that of the proposed alternative is greater than 1.5 then the proposed alternative can be designated without further analysis. If the ratio is between 1.0 and 1.5, then two additional tests have to be performed: if the current routing is greater than 100 miles, a deviation of 25 miles is acceptable for a route, and if less than 100 miles, a 25% increase in route length is not considered unduly burdensome on commerce.

DATA SOURCES

Population data was provided by the City of New Haven at the block-level based on 2010 Census and the most recent American Community Survey data. Population data was supplemented with street and highway network files, zoning and address data. Traffic volume data (ADT) was also provided by the City of New Haven, based on counts performed by the state DOT in 2009 and 2011 and a contractor on the Route 34 project in 2010. Crash data along the corridor for 2010 was obtained from the City of New Haven.

METHODOLOGY

Analysis was conducted in a straightforward manner, first establishing an appropriate spatial buffer for the spatial analysis. The buffer sizes in Table 1 were adopted from the 1996 HazMat Routing Guide (USDOT 1996). With petroleum products being the focus of this study, a buffer size of 0.5 mi. was selected for analysis.

Table 1: Impact area (buffer size) by HazMat Material Class (from USDOT 1996)

HazMat Class		Impact Area (Buffer size)
Explosives	(EXP)	1.0 mi.
Flammable Gas	(FL)	0.5 mi.
Poison Gas	(PG)	5.0 mi.
Flammable/Combustible Liquid	(FCL)	0.5 mi.
Flammable Solid; Spontaneously Combustible; Dangerous when Wet	(FS)	0.5 mi.
Oxidizer/Organic Peroxide	(OXI)	0.5 mi.
Poisonous, not gas	(POI)	5.0 mi.
Corrosive Material	(COR)	0.5 mi.

Next, units of risk were established for the comparison of the two alternative routes. Population exposure (population residing within the buffer distance of the routes) is often used as the unit of analysis for HazMat routing decision support. However, this unit ignores the important temporal aspect associated with HazMat transport. Longer road segments with lower speeds will obviously result in longer traversal times, increasing the exposure of the population along the link. As seen below in equation (1), the product of population exposure with link travel time was used in the numerator, with the length of each segment in the denominator (allowing for comparison between links of different lengths. This function results in risk units "person-minutess per mile".

We define the link risk, R_{ij} as follows:

$$R_{ij} = \sum_{(i,j) \in A} \left(\sum_{b \in B} d_b p_b \right) t_{ij} / l_{ij} \qquad (1)$$

Where,

t_{ij} = travel time on the link (i, j)

l_{ij} = length of each link (i, j)

b = population blocks inside the impact area

d_b = decay value of each block, b

p_b = population in block, b

In the above formulation we apply a decay function to acknowledge that the population immediately adjacent to a link of the HazMat route experiences much greater risk exposure than the population at the boundary of

the impact area. Figure 3 depicts the situation for a hypothetical link in a HazMat route. As a HazMat vehicle traverses the link from i to j if we assume a circular impact area for that vehicle, those households that are immediately adjacent to the route at location i are actually within the impact area 1/2-mile *before* the vehicle reaches the link and are then remain within the impact area for the entire time it takes the vehicle to travel twice the buffer distance (1.0 mile in this case, using a 0.5 mile buffer). In contrast, those household at the boundary of the impact buffer (dashed line in Figure 3) do not actually enter the circular impact area until the vehicle is perfectly perpendicular to the household. That household remains only in the impact area for an instant as the vehicle passes.
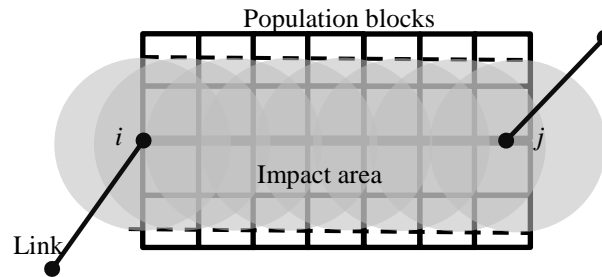

Figure 3: Illustration of impact area and risk exposure

It follows naturally that the households nearest the route should then be considered to have greater risk exposure than those near the impact area boundary. Since we do not have individual household data, we will use distance to block centroid as a proxy and the associated block population to calculate risk exposure using the exposure decay equation (2), depicted in Figure 4. As one can see, risk exposure is 100% immediately adjacent to the link, decaying (using a circular function) to 0% at the impact area boundary.
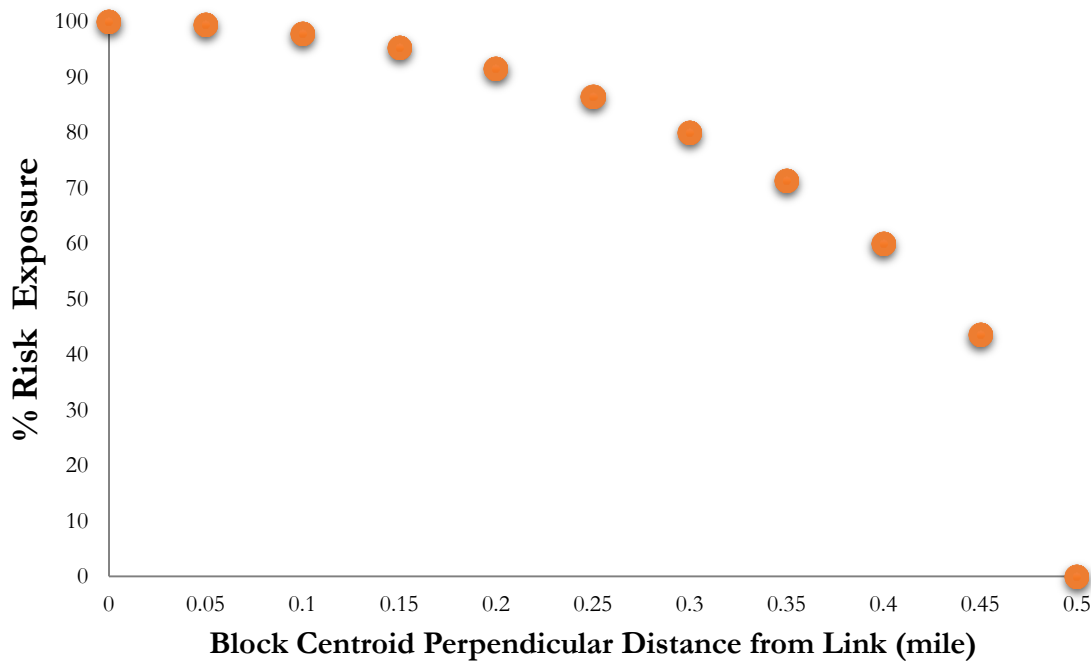

Figure 4: Graphical depiction of decay function

$$d_b = \sqrt{1 - \left(\frac{\gamma_b}{B}\right)^2} \qquad (2)$$

Where

γ_b = perpendicular distance of block centroid b to link (i, j) (mi.)

B = selected impact area (buffer) size (mi.)

It is important to note that when calculating the population exposure associated with each link, the following precautions were taken:

1. Link endpoints were dissolved when calculating population exposure to avoid double-counting associated with block centroid that fall within the buffer distance of the ends of multiple links (see Figure 5 below).
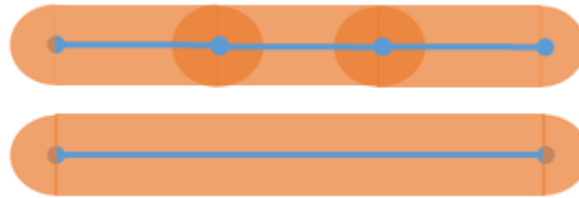

Figure 5: Link endpoints – Possibility of double-counting (top) and Dissolved Route (bottom)

2. Block population bisected by the buffer boundary was included in the risk exposure calculation proportional to the ratio of area inside the buffer to the total block area. Figure 6 demonstrates this precaution.
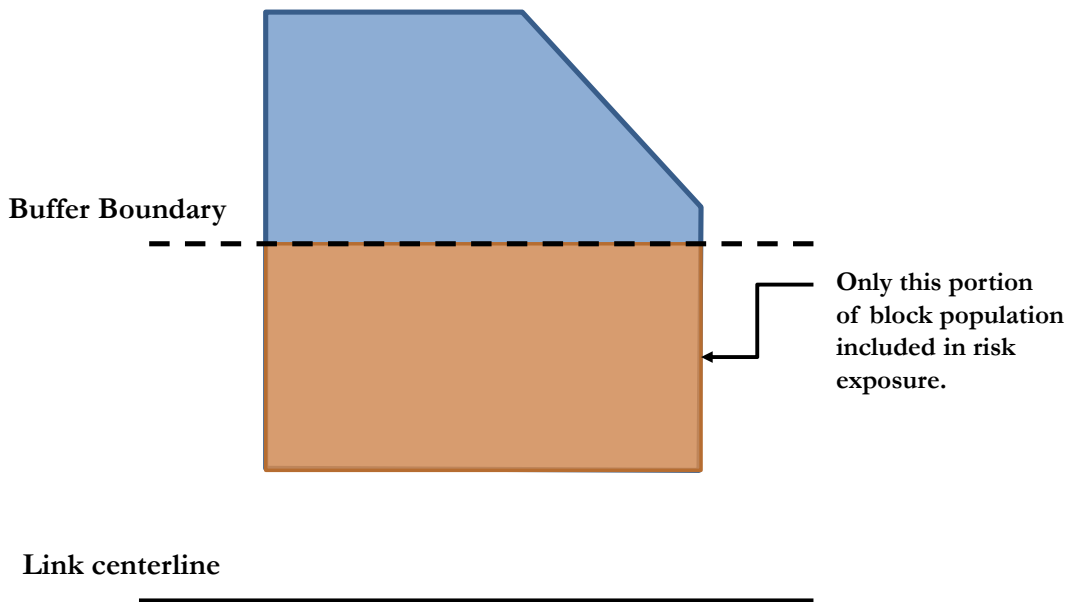

Buffer Boundary

Only this portion of block population included in risk exposure.

Link centerline

Figure 6: Proportional block populations when bisected by buffer boundary

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RESULTS

The Route 34 HazMat Route actually consists of three slightly different routes using different combinations of entries/exits along its length. All three variations were analyzed by the same process. The least risky Route 34 path is presented in the results below to provide the most conservative comparison with the proposed alternative. It is also important to recognize that there are two directions along each of these routes which could theoretically result in different risk estimates. Analysis was run in both directions, though the difference in the results was negligible. Results are only presented for the East-to-West routing for this reason and because the primary concern of the City was the flow of HazMat from the Port of New Haven west towards Derby, CT.
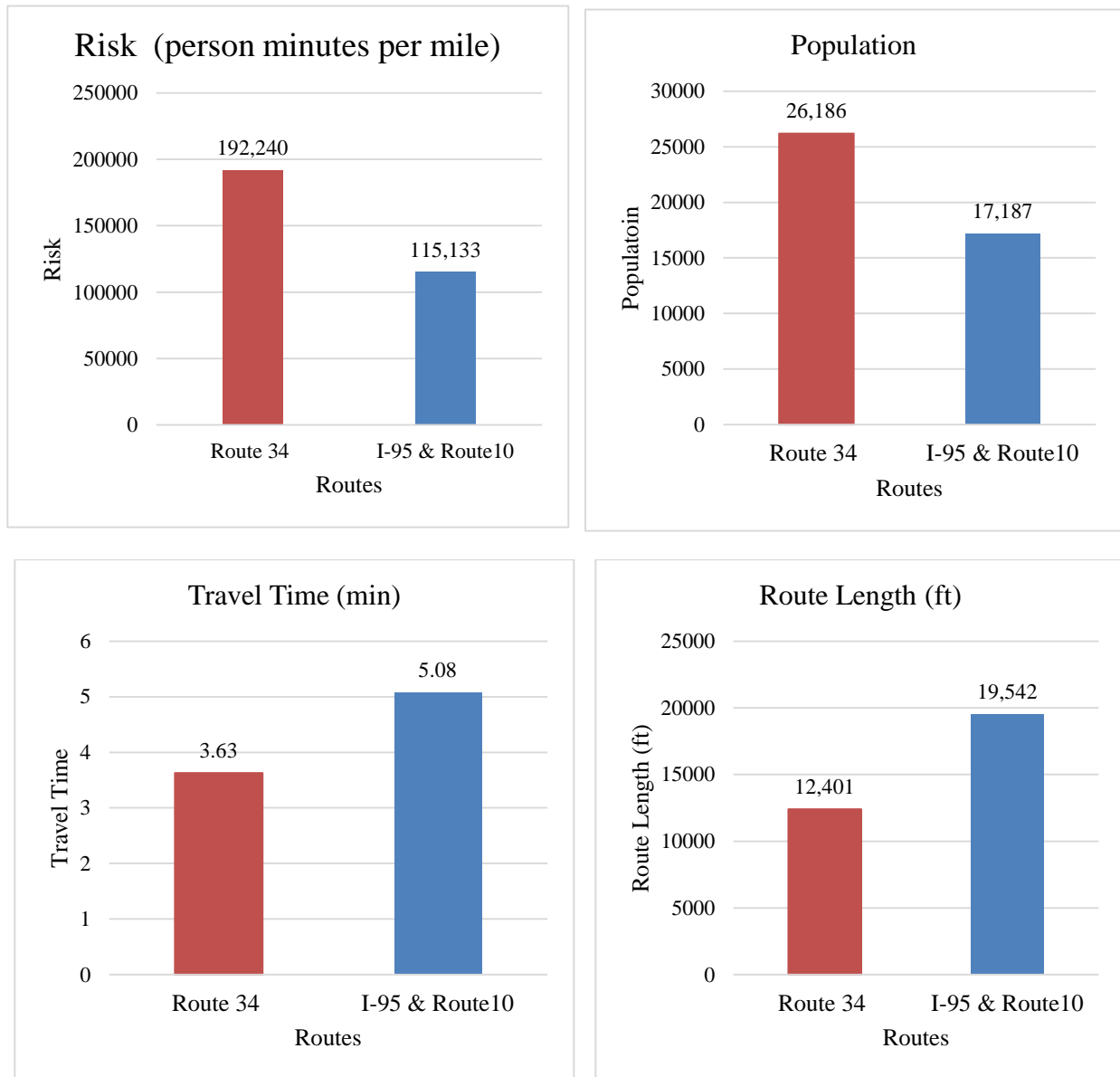

Figure 7: Comparison between Route 34 and I-95/Route 10

It can be seen in Figure 7 that the I-95/Route 10 option is nearly 7100 ft longer, an increase of approximately 55% over the least risky Route 34 option. The difference in travel time between these two routes is quite small, amounting to approximately 1.5 minutes, or about 40%. The most significant difference between the two routes is the population exposure within the 0.5-mile buffer of the route. It can be seen that Route 10 has nearly 9,000 less population within the buffer distance along its route. This is the primary driver in the risk reduction associated with the Route 10 option, a different of nearly 77,000 person-minutes per mile.

CONCLUSIONS

According to USDOT (1996) if the ratio of the relative risk of the current routing to that of the proposed alternative is greater than 1.5 then the proposed alternative can be designated without further analysis. We can compute this ratio for both population exposure and the risk measure adopted in this study. The results are given in Table 2.

Table 2: Risk and exposure comparisons between routes

	Risk	
	Risk (Person Minutes per Mile)	**Population Exposure**
Route 34	192240	26196
I-95/Route 10	115133	17187
Ratio	1.67	1.52

The ratio of the current Route 34 routing to the proposed Route 10 routing is greater than 1.5. For less dramatic reductions (a ratio between 1.0 and 1.5), USDOT (1996) suggests that for a route less than 100 miles, the increase in route length should not exceed 25%. It follows that I-95/Route 10 meets federal criteria as a viable alternative HazMat route. It is important to note that this analysis treats population exposure as a static parameter and does not account for the movement of people throughout the day. A further analysis investigating daytime, evening and weekend population movement would provide a more complete picture of the HazMat risk exposure.

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