Role of Brownfield Developments in Reducing Household Vehicle Travel

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Abstract: The transportation sector is the second largest source of greenhouse gas (GHG) emissions in the United State. Developing underutilized urban industrial sites with certain characteristics (i.e., close proximity to transit, job and services, low remediation cost, and high density) can potentially reduce the transportation sector's impact on the environment by lowering vehicle kilometers traveled (VKT) and related GHG emissions. This study examines the effect of residential brownfield developments on VKT reduction and the resulting costs (including the cost of driving time, fuel, and external air pollution costs) and further compares the resulting costs with the initial one-time cleanup cost of brownfield sites. Sixteen brownfield and conventional development sites were analyzed in Baltimore, Chicago, Minneapolis, and Pittsburgh. Travel demand models were used to estimate VKT differences among the developments. Air pollution valuation data were used to estimate external environmental cost differences. On average, residential brownfield developments reduce VKT by 52% compared to conventional greenfield developments. Also on average, brownfield developments result in a time and fuel cost reduction of 60% and an external environmental cost saving of 66%. Comparing these cost savings with the initial one-time cleanup cost of brownfields, it is shown that development density and the cost of remediation significantly affect the number of years required for the VKT cost savings to offset the remediation cost. **DOI: 10.1061/(ASCE)UP.1943-5444.0000113.** *© 2012 American Society of Civil Engineers.*

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Introduction

Brownfields are properties for which expansion, redevelopment, or reuse may be complicated by the presence or potential presence of hazardous substances, pollutants, or contaminants (USEPA 2009). According to the U.S. Environmental Protection Agency (EPA) and the U.S. Government Accountability Office (GAO) there are more than 450,000 brownfield sites in the United States (USEPA 2009; USGAO 2004). These sites include former industrial or manufacturing plants, dry cleaners, gas stations, laboratories, and residential buildings. Developing brownfields incurs initial assessment and remediation costs and involves barriers such as uncertainty about the presence and type of contamination, uncertainty over cleanup standards, limited cleanup resources, and potential liability issues [U.S. Department of Housing and Urban Development (USHUD) 2010; Office of Technology Assessment (OTA) 1995]. On the other hand, developing these underutilized lands can positively impact economic development and the environment (Lange and McNeil 2004; De Sousa 2002). Brownfield developments have been shown to revive communities (Kaufman and Cloutier 2006), increase employment (De Sousa 2005), generate local tax revenue (De Sousa 2005), and keep green spaces intact [George Washington University (GWU) 2001].

To make a proper decision about developing a brownfield site, it is important that all environmental, economic, and social benefits and costs are taken into account. In this paper, however, only the impact of residential brownfield developments on travel activity reduction and the consequential costs including the cost of time and fuel, as well as the external environmental costs, are analyzed. Examining contributing factors such as travel distance and number of trips generated by each of the brownfield and greenfield sites, vehicle kilometers traveled (VKT) were compared for a sample of brownfield and greenfield residential developments in four cities: Chicago, Pittsburgh, Baltimore, and Minneapolis. Greenfields are undeveloped lands such as farmlands, woodlands, or fields located on the outskirts of urbanized areas (USHUD 2010). In the absence of infill developments (e.g., brownfields), greenfield developments are where growth occurs. The external air pollution costs of driving for each brownfield and greenfield site using air pollution valuation data (Muller and Mendelson 2007) were estimated. In addition to the valuation of criteria air pollutants, CO_2 emission costs using existing literature values were included. Furthermore, VKT reduction cost with initial one-time cost of brownfield remediation was compared. While the VKT reduction benefits of brownfield developments have been evaluated by a number of studies in the United States as discussed in the next section, no study to date has performed a comparison between the environmental, time, and fuel benefits of brownfield developments and the cost of remediation. The goal is to determine if the environmental cost savings as well as time and fuel cost savings from VKT reductions offset the extra initial one-time cleanup cost of brownfield developments.

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Vehicle Kilometers Traveled and Brownfield Developments

From 1995 to 2008, VKT in the United States increased from about 3 trillion to approximately 4.8 trillion, with an average annual increase of about 2% [Federal Highway Administration (FHWA) 2008]. It is projected that VKT will continue to increase at an average annual rate of 1.6% over the next 20 years (U.S. Department of Energy 2008), resulting in a VKT of 7 trillion by 2030. The projected impact from increasing VKT is expected to outpace gains from improved fuel economy and alternative fuels, resulting in an increase of greenhouse gas (GHG) emissions (AASHTO 2008). As a result, the American Association of State Highway and Transportation Officials (AASHTO) has set a goal of reducing the VKT growth rate to that of population growth, approximately 1% per year, by 2030. In addition, the Federal Surface Transportation Policy and Planning Act of 2009 was introduced to reduce national per capita VKT on an annual basis and to reduce GHG emissions resulting from surface transportation by 40% by 2030 (S 1036 2009).

Reducing VKT and the resulting GHG emissions can be accomplished by various strategies, including, but not limited, to, parking management, pricing alternatives, and public transit improvement, as well as changing land use patterns. Changing land use patterns can be accomplished through smart growth concepts such as compact developments, mixed-use developments, walkable communities, and transit-oriented developments (Johnston 2006). Compact urban development has been correlated to a reduction of 20–40% in VKT compared with sprawl (Ewing et al. 2008). A National Research Council study concluded that compact developments with a high density are likely to reduce VKT, energy consumption, and CO_2 emissions [National Research Council (NRC) 2009]. Handy et al. (2005) and Shammin et al. (2010) also support the benefits of compact developments with respect to reducing energy consumption and travel activity. On the other hand, critics of compact developments note the costly effects of increased traffic congestion, higher taxes, higher consumer costs, and more intensive developments (O'Toole 2009; Gordon and Richardson 1997).

Large brownfield developments are typically redeveloped as mixed-use or compact developments, which consist of residential, retail, offices, entertainment centers, and community centers [Missouri Department of Natural Resources and Conservation (DNRC) 2006]. As Paull (2008) documents, increasing mixed-use and residential use of the brownfield sites meets smart growth objectives. A number of studies have documented that brownfield developments are mostly compact. Brownfield developments conserve land in a ratio of 1 acre per brownfield redeveloped to 4.5 acres per conventional greenfields (GWU 2001). De Sousa (2005) reports brownfield residential density of 59 households per acre in Chicago. In addition to density, distance to city centers, access to transit, diversity of land use within the developments, and the design of the mixed-use developments, both internally and in connection with the existing urban grids, are factors that can potentially influence the impact compact brownfield developments might have on VKT reduction. Several studies show that brownfield developments lower VKT compared to conventional

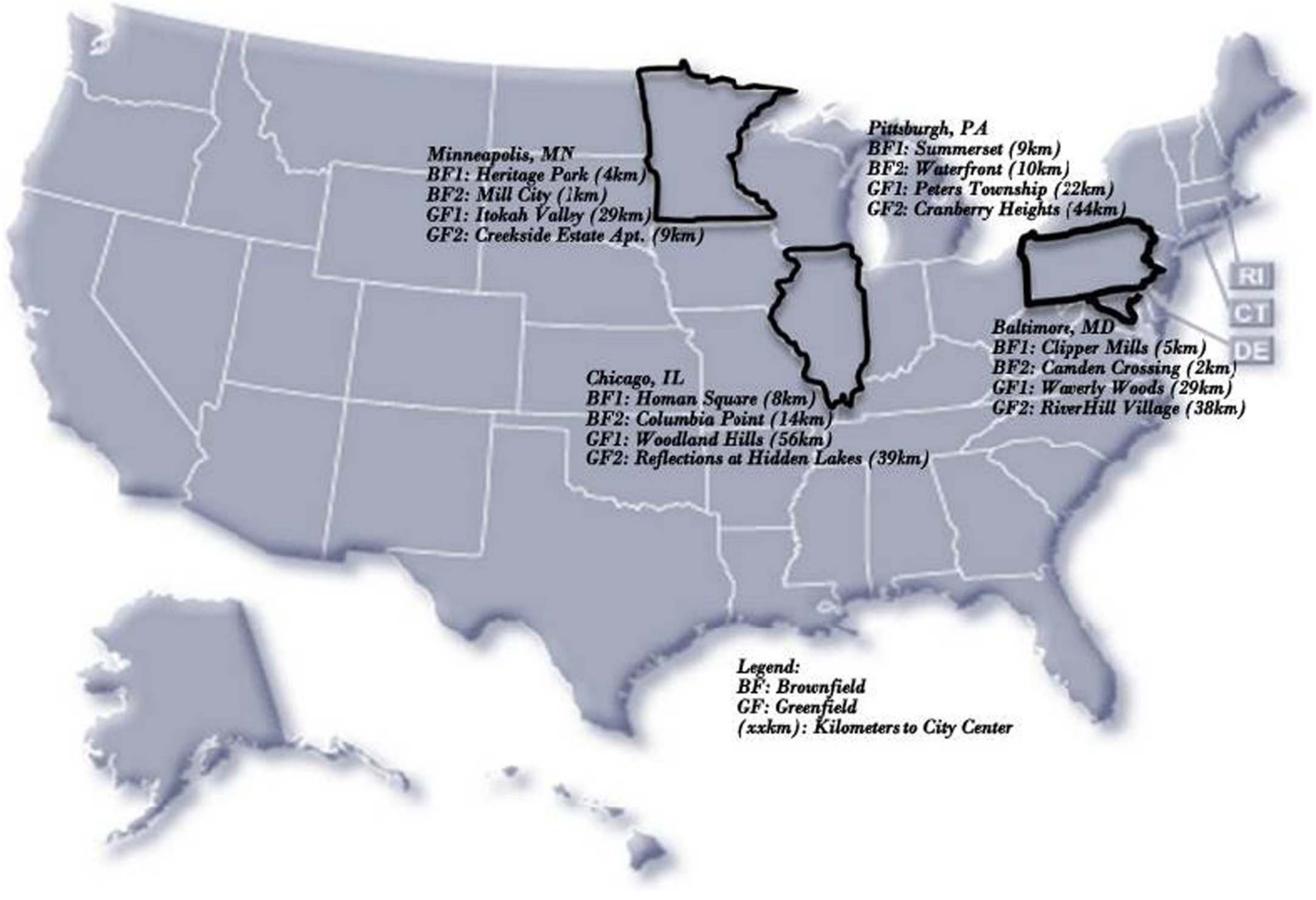

Fig. 1. Map of brownfield and greenfield developments analyzed in this study and their distances to city centers

greenfield sites (USCM 2001; USEPA 2006; EPA 2011). Moreover, Nagengast (2011) compares commuting travel times between brownfields and greenfields in six cities and concludes that commuting travel time is less for brownfields compared to greenfields. A comparison of the results of this study and the previous figures is presented in the discussion section of this paper.

Remediation Cost of Brownfield Sites

To develop a brownfield site, a risk assessment generally followed by site remediation is necessary. The remediation solution largely depends on the types of contaminants found. The cost of remediation varies significantly depending on the type of contaminant, level of exposure, and procedures needed to clean up the contaminants (USEPA 2001; Rast 1997). While several studies report the cost of brownfield cleanup as a percentage of public funds or total investment funds, the exact remediation costs are not reported in most cases. International Economic Development Council reports the median cleanup cost per acre is US $57,000 [International Economic Development Council (IEDC) 1999]. The City of Chicago reports the remediation cost of multiple projects from $25,000 to $530,000 per acre (City of Chicago 2003). A complete list of remediation costs from multiple studies used in the analysis of this paper is presented in the methodology section. Furthermore, a wide range of remediation cost and its impact on the results of the comparison is analyzed in the uncertainty analysis section of the paper.

Although incurring initial remediation cost, brownfield developments might require lower initial construction investments as they are typically built compact and, in most cases, benefit from already existing infrastructures such as water pipelines, power supply, roadways, and sewer systems (Burchell et al. 2005; Leinberger 2009; Altshuler and Gomez Ibanez 1993). Opponents of brownfield developments critique the lower initial brownfield construction investments and believe that for sites with higher density the existing infrastructure may not be properly sized or reusable, and because of the typical location of brownfields within the urban core and the scarcity of land in those areas, development cost are higher (TCRP 1998; Greenberg 2002).

Methodology

Site Selection

Based on data availability, a sample of 16 U.S. brownfield and greenfield residential developments were selected in the four metropolitan areas of Baltimore, Chicago, Minneapolis, and Pittsburgh. The sample was restricted to metropolitan areas for which experienced and knowledgeable representatives could identify two brownfield developments and two comparable greenfield developments. With the assistance of local representatives managing brownfield programs and local urban planners in each of the cities, two brownfield sites and two comparable greenfield sites were identified in each of the four cities (total of eight brownfield and eight greenfield sites) with the following two criteria: (1) minimum of 100 dwelling units within each development, and (2) developments must have been completed within the past 20 years. The average distance between the selected brownfield sites and city centers is 6.4 km while the average distance from the selected greenfield sites to city centers is 34 km. Fig. 1 illustrates the selected 16 sites used in this study, their approximate location, and each of their distances to city centers.

While demographics (e.g., age, income) of those living in various land uses are important in the comparison of brownfield and greenfield developments, these factors were not included in the site selection process. The methodology explained hereafter focuses on travel cost savings and its comparison with the cost of remediation for those who are already living at the aforementioned sites.

Vehicle Kilometer Traveled Data Sources

To determine the average difference in travel activities between residential brownfield and greenfield developments, 2010 travel demand model (TDM) data including the number of home-based work and non work automobile trips and trip distances were obtained from the metropolitan planning organizations (MPO) for each city. Travel demand models simulate real world travel patterns. The model takes into account travel behaviors that influence drivers' choice of destination, mode of transportation, and selected routes (Wang and vom Hofe 2007). TDMs and geographic information systems (GIS) were used to identify traffic analysis zones (TAZ) containing the study sites. A traffic analysis zone is the unit of geography, similar to census tracts, used in travel demand models (Harvey and Shaw 2001). By analyzing trip productions and attractions (the number of trips produced and attracted to each TAZ), the number of home-based automobile trips and resulting VKTs generated and distributed by the study sites to all other TAZs were calculated. The trips were categorized into two groups: home-based work (HBW) trips and home-based non work (HBNW) trips. To compare results among brownfield and greenfield sites, VKT estimates were normalized by the number of households. Specific information on each of the four MPOs involved in this study is provided in the Appendix. Because of the agreement with MPOs, only the number of vehicular trips generated by each site within a TAZ and the distances were provided. Other relevant data had to be estimated. Texas Transportation Institute (TTI) (explained in the next section) data were used for speed and cost of time.

Direct Cost Analysis (Time and Fuel)

To compare costs of brownfield and greenfield developments, costs were categorized as direct (including cost of time and fuel) and indirect (external environmental) costs. Direct costs are typically those that are incurred by those occupying the development versus indirect costs, which are those that are incurred by the whole society.

To estimate the direct costs, VKTs associated with each brownfield and greenfield site were first converted to travel times and then to the cost of time. To determine travel times, the percentage of freeway and arterial kilometers for each site was investigated and speed of 97 km=h and 56 km=h was assumed for freeways and arterials, respectively (Schrank and Lomax 2009). The average value of time was assumed to be 15.50 per hour for the base case, while a range of values were analyzed to account for uncertainties (Schrank and Lomax 2009).

To estimate the fuel energy and cost of fuel, vehicle emission factors were determined using EPA's Mobile 6.2 (MOBILE6) on-road emissions modeling tool. MOBILE6 determines emissions from fuel combustion, evaporative losses, and brake and tire wear for light and heavy duty vehicles, trucks, buses, and motorcycles (USEPA 2003). Because only automobile travel data are analyzed, only light duty vehicles were included in the MOBILE6 analysis. Fuel energy in megajoules (MJ) per kilometer m was calculated for the average speeds of 97 km=h and 56 km=h for freeway and arterial VKTs, respectively. A Reid vapor pressure of 8.7 psi with July freeway conditions was assumed. The price of gasoline was assumed to be $2.80 per gallon. Fuel use (FU) is a function of fuel energy (FE) and daily vehicle kilometers traveled (DVKT) and fuel cost (FC) is a function of FU and the price of gasoline:

$$FU_{(a)} = (FE_i \times DVKT_{i(a)}) + (FE_j \times DVKT_{j(a)}) \quad (1)$$

$$FC_{(a)} = (FU_{(a)} \times P)/C \quad (2)$$

where $FU_{(a)}$ = fuel use for site a (megajoule/day); FE = fuel energy (megajoule/kilometer); $FC_{(a)}$ = fuel cost for site a ($/day); P = price of gas ($2.80/gallon); C = 121.3 MJ/gallon of gasoline $DVKT_{(a)}$ = daily vehicle kilometer traveled for site a (kilometer/day); and

i and j = freeway and arterial, respectively.

Indirect Cost Analysis (External Environmental Cost)

To calculate the cost of external air emissions, the air pollution emission experiments and policy (APEEP) analysis model was used (Muller and Mendelsohn 2007). APEEP connects county-level emissions of air pollutants through air quality modeling to exposures, physical effects, and monetary damages (NRC 2010). For each county and pollutant, APEEP estimates mortality, morbidity, and environmental damages (e.g., crop loss, timber loss, materials depreciation, visibility, forest recreation). A value of statistical life (VSL) of $6 million, in accordance with EPA's central VSL, is used for the APEEP analysis (Dockins et al. 2004). The cost of CO was assumed to be $520/t (Matthews and Lave 2000), as it was not provided by APEEP. Because CO and NO_X are both predominantly tropospheric ozone precursors, the CO value was scaled for each county analyzed using the ratios for NO_X observed in the APEEP data (Mashayekh et al. 2011). A mean CO_2-eq cost of $30/t was used in this study (NRC 2010). To account for uncertainties, data ranges for the cost of CO, CO_2, gas, time and APEEP costs are assumed and will be explained in the results section of this paper.

Joining APEEP-specific county-level results with the national MOBILE6 vehicle emission factors in grams per kilometer, and freeway and arterial VKTs calculated for each site, the external environmental VKT cost for each of the brownfield and greenfield sites were calculated and compared. Carbon dioxide (CO_2), sulfur oxides (SO_X), nitrogen oxides (NO_X), particulates ($PM_{2.5}$), ammonia (NH_3), and carbon monoxide (CO) emissions were considered in this study based on the availability of pollution valuation data.

MOBILE6 fails to account for speed-specific fuel economy, emissions of SO_2, $PM_{2.5}$, and NH_3 or driving cycles specific to each metropolitan area (Mashayekh et al. 2011). To capture the variation of fuel economy and CO_2 emissions with speed, the relationships developed by Ross (1994) were employed. The amount of fuel consumed by a vehicle and the resulting CO_2 emissions are the result of the power needed to overcome tire rolling resistance, air drag, vehicle acceleration, hill climbing, and vehicle accessory loads (Mashayekh et al. 2011; Ross 1994). These factors in combination produce a fuel energy-to-speed profile that is used to adjust the MOBILE6 fuel economy and CO_2 emission baseline factors to develop speed-specific factors (Ross 1994).

To address the effects of fleet age, vehicle emission factors were increased by 4.9% annually for CO, 1.4% for NO_X, 4.5% for $PM_{2.5}$, and 5.9% for VOCs (Chester et al. 2010). The average vehicle age is assumed to be 5 years (USDOE 2008). Combining the cost of each pollutant from APEEP (/kilogram) with emission factors from MOBILE 6 (gram/kilometer) and daily VKTs (kilometer/day), the external environmental cost of each pollutant was calculated for each development using the following equation:

$$C_{i(a)} = DVKT_{(a)} \times EF_i \times C_i \quad (3)$$

where $C_{i(a)}$ = cost of pollutant i for development a ($/day); $DVKT_{(a)}$ = daily vehicle kilometer traveled for development a (kilometer/day); EF_i = emission factor for pollutant i (gram/kilometer); and C_i = cost factor for pollutant i (1,000/gram).

VKT and Remediation Cost Comparisons

After direct and indirect costs (costs incurred by the residents and costs incurred by the society) were calculated and compared between the brownfield and greenfield developments, brownfield cost savings from VKT reductions were also compared with the initial remediation cost. The goal was to examine if the cost savings from VKT reductions offset the extra initial one-time cleanup cost of brownfield developments.

The remediation cost depends significantly on the type of contaminant and the level of exposure, both of which factored in selecting the strategy used to clean up the site. The cost of cleanup includes direct costs, contractor overhead and profits, and contingencies. Because these values vary significantly from site to site, a range of remediation costs from multiple studies and references was used (see Table 1).

To compare the one-time remediation cost with the cost savings from the VKT reductions calculated earlier, the average cost of $190,000 per acre was used for the base case and the 95th percentile cost of $550,000 per acre and 5th percentile cost of $24,000 per acre were used for the worst and best cases, respectively.

The residential density of the eight selected brownfield sites studied in this paper ranges from 6 to 59 households per acre with the median of 12 households per acre. Great Communities Organization reports a range from 19 to 129 household per acre for compact developments (GCC 2009). Leading studies in compact developments report an average of 11–15 households per acre for compact developments (CSI 2009; Ewing et al. 2008; NRC 2010). In this study, a base average of 12 households per acre was used to normalize the base remediation cost.

Results

VKT Comparison Results for Brownfield and Greenfield Sites

VKTs were calculated for eight brownfield and eight greenfield sites within the four selected cities of Baltimore, Chicago, Minneapolis, and Pittsburgh. Table 2 compares the estimated HBW automobile (i.e., light-duty vehicle) VKTs, trip distance, and the number of trips per household for brownfields and greenfields measured from the vehicle trips and distances provided by the MPOs for each city. The number of vehicle trips were based on TAZs that each site was located in.

Table 1. Remediation Cost Based on Various Documentations

Study	Remediation cost ($/acre)	Note
Chicago 2003	25,000–530,000	Various projects
Auld et al. 2010	580,000	Pittsburgh
Lehr 2004	250,000–500,000	Capping
IEDC 1999	57,000	—
RSMeans 2010	45,000	Capping (18 in.)
Terry 1999	22,000	Phytostabilization
Terry 1999	56,000	Soil capping
Terry 1999	65,000	Asphalt capping

Table 2. Brownfield and Greenfield Development Travel Pattern Comparisons—Daily Home-Based Work (HBW) Auto Trips per Household

Type	Average VKT (km=HH)	Average distance (km=trip)	Average # of trips=HH
Brownfield (BF)	10.0	11.0	0.9
Greenfield (GF)	24.0	18.0	1.7
National	19.0	21.0	1.0
Reduction (GF to BF)	60%	36%	47%

Note: km = kilometer; HH = household; BF = brownfield; and GF = greenfield.

The results shown in Table 2 indicate that brownfield travelers drive fewer daily kilometers than those living in greenfields (60% less). This reduction is statistically significant at greater than 95% confidence (p □ 0.00004). The difference in VKTs is the result of the differences in the number of trips per household and the differences in the distance of those trips. Tables 2 and 3 also compare the daily VKTs, daily trips, and distances with the national average data [National Household Travel Survey (NHTS) 2009]. In the case of HBW trips, the national average VKT falls in between brownfield and greenfield sites, perhaps from an overall fewer number of trips per household in the nation.

The result of comparisons between HBNW trips shows that brownfield sites on average generate 42% less VKT than greenfield sites (Table 3).

The reduction shown in Table 3 is statistically significant at greater than 95% confidence (p □ 0.005). Because of the general close proximity of shopping centers, schools, and recreational sites to greenfields, the difference of VKTs between brownfield and greenfield developments in the case of HBNW trips is not as large as HBW trips.

In the case of HBNW trips the national average data are higher than both groups; perhaps because the national averages include rural areas in which people need to drive farther distances to get to nonwork destinations compared to the urban areas used in this study.

The total annual weekday average VKT reduction associated with brownfield sites including work and nonwork trips is 52%.

Table 3. Brownfield and Greenfield Development Travel Pattern Comparisons—Daily Home-Based Nonwork (HBNW) Auto Trips per Household

Type	Average VKT (km=HH)	Average distance (km=trip)	Average # of trips=HH
Brownfield (BF)	18.0	7.0	2.5
Greenfield (GF)	31.0	10.0	3.0
National	40.0	15.0	3.0
Reduction (GF to BF)	42%	33%	17%

Note: km: kilometer; HH: household; BF: brownfield, GF: greenfield.

Direct and Indirect Travel Costs Results for Brownfield and Greenfield Sites

Table 4 shows a breakdown of the average daily direct and indirect costs of brownfield and greenfield sites per household and the percent reduction of each of these costs between greenfield and brownfield sites.

Direct costs (those incurred by the residents of the sites including time and fuel) have higher magnitudes compared to the external environmental costs (incurred by society). Also, in the external environmental costs category, CO_2, VOC, CO, and NH_3 costs have higher magnitudes than NO_X, SO_2, and particulates.

Based on the VKT calculations, the results of the cost analyses conducted for the four cities shows that the direct costs of brownfields, including time and fuel, are about 60% lower than greenfield sites, while the external environmental costs are reduced by about 67%.

Adding up the annual weekday costs for brownfields developments show an annual household direct (time and fuel) saving of $2,400 for the residents of the brownfield sites and indirect (external environmental) cost saving of $450 per household.

A percentage of those who live in brownfield developments will use transit, therefore they incur cost of transit plus cost of time. Also depending on the level of ridership, transportation authorities might increase the number of buses, resulting in increased emissions and external environmental costs.

Comparison of VKT Costs and Remediation Costs for Brownfield Sites

To examine whether the benefits from the VKT reductions associated with brownfield sites account for the initial cost of brownfield sites, an average remediation cost of $190,000 per acre was assumed. For the remediation cost to offset the benefits from the VKT reduction (2; 900=household) in the first year, a development needs to have at least 65 housing units per acre. With the average density of 12 units per acre (CSI 2009), the benefit will offset the cost in about 6 years, assuming a discount rate of 7%. Fig. 2 illustrates the net present value of various scenarios.

Because the cost of remediation and the density of brownfield developments vary significantly as seen in Fig. 2, sensitivity analysis, explained in the next section, was conducted to examine the effect of cost and density variances on the comparison between remediation costs and VKT reduction cost savings.

In addition in comparing the VKT costs and remediation costs, it is important to realize that these costs are incurred by different groups. For instance, while the direct cost savings of VKT reductions are incurred by the residents of brownfields, the indirect cost savings (external environmental cost savings) are a benefit to the society. Meanwhile, the remediation cost is typically paid by the developers, landowners, or taxpayers through public agencies. Differentiating among these costs should help public agencies and policymakers to better incentivize and help with the cost of brownfield cleanups for the benefits of the society at large (De Sousa 2002; Perskey and Wiewel 1996).

Table 4. Comparison of Direct and Indirect Average Daily Costs per Households between Brownfield and Greenfield Sites

	Average direct costs ($=day)		Average indirect external environmental costs ($=day)							
Area	Time	Fuel	CO_2	NO_X	VOC	CO	SO_2	PM	NH_3	Total
Brownfield (BF)	5.0	1.1	0.1	0.06	0.2	0.2	0.002	0.02	0.4	0.9
Greenfield (GF)	12.0	2.8	0.3	0.09	0.5	0.3	0.005	0.06	1.4	2.6
% reduction (GF to BF)	60	60	60	40	70	40	60	70	75	67

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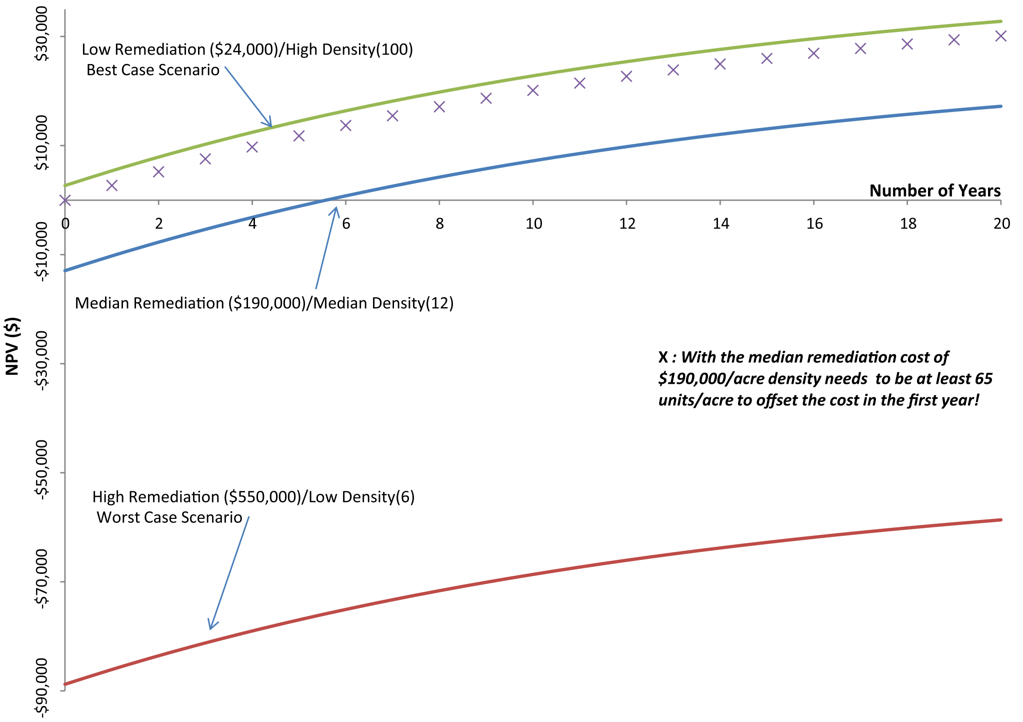

Fig. 2. Net present value (NPV) for various remediation/density assumptions

Uncertainty□ Bounding Analysis

To examine the range of costs associated with the VKT reduction from brownfield developments and to compare the worst and best case scenarios, a bounding analysis was conducted with the assumptions shown in Table 5 emissions costs were used for the basecase and for the worst and best case scenarios lowest and highest U.S. county costs were assumed. CO_2 unit costs are based on about 50 studies showing a mean cost of $30/ton, and 5th and 95th percentile costs of $1/ton and $85/ton (NRC 2010). Cost of CO was assumed to be an average of $520/ton, min of $1/ton and max of $1050/ton (Matthews 2000). Despite the large range of CO cost, the uncertainty analysis shows that cost savings are not sensitive to the cost of CO.

The results show that the total cost savings of driving associated with brownfields ranges from $1,300 to $5,700 per household. Assuming a 7% discount rate, using the lowest remediation cost ($24,000/acre) and the highest density (100 HH=acre), it will only take 1 year to offset the cost of remediation (even with the lowest cost saving of $1,300), while with the highest remediation cost (550; 000=acre) and lowest density (6 HH=acre), the remediation cost is never covered by the annual cost savings even with the largest cost saving of $5,700. The highest remediation cost of $550,000 and the lowest cost saving of $1,300 require a density of 55 units per acre to account for the cost in 10 years. Given the significant amount of uncertainty in the cost of remediation and the density of the development, to assure the highest amount of VKT reduction savings, both variables should be carefully considered when choosing a brownfield site.

Table 5. Uncertainty—Bounding Analysis Assumptions

Cost factor	Base	Best case	Worst case
APEEP emission costs	County-specific	Lowest county costs	Highest county costs
CO_2 value ($/t)	30	1	85
Cost of fuel ($/gallon)	2.80	Min (2008–2010)	Max (2008–2010)
Cost of CO ($/t)	520	1	1050
Cost of time ($/h)[a]	15.5	8.25	30.0
Remediation cost ($/acre)	190,000	24,000	550,000
Density (HH/acre)	12	100	6

[a] Based on minimum wage and annual salaries.

Discussion

Comparison of VKT and GHG Reductions

Although methodologies to estimate VKT and GHG reduction are different between this study and some previous studies (i.e., TAZ level data versus census level data; valuation and accounting versus life cycle assessments), the existing literature provides an opportunity to compare and validate the results of this study. Relevant existing reported VKT reductions are shown in Table 6.

The variation observed in the estimates reported in Table 6 can be the result of many factors including methodology used, trip generation assumptions in different jurisdictions, vehicle emission profiles varying in different geographical boundaries, and uncertainties in estimating externalities. While these uncertainties and inconsistencies are inevitable, the literature results show a 43 □ 38 reduction for VKT, which is consistent with the results of this study (38%–63%). Furthermore, the literature results show a 46 □ 41% emissions reduction, which is consistent with the results of this study (35–75%).

Travel times associated with brownfield sites are further compared to the national averages and census journey to work data in Table 7 (NHTS 2009; U.S. Census Bureau 2009).

While the travel time estimates for HBNW trips used in this study are very similar to the NHTS survey average, the HBW travel time is half of the other estimates, likely from the close proximity of the small sample size to work and city centers.

Table 6. Comparison of VKT and GHG Reductions between Various Studies

Study	Geographic area	Type of land use	Average reduction in VKT (%)	Range of reduction in VKT (%)	Range of reduction in GHG and air pollutants (%)
This study	Baltimore, Pittsburgh, Chicago, Minneapolis	Brownfield	52	38–63	35–75
USEPA 2011	Seattle, Minneapolis, St. Paul, Emeryville, Baltimore, Dallas	Brownfield	47	32–57	32–57
EPA 2001a; EPA 2002; EPA 1999; NRDC 2003; Schroeer 1999; IEC 2003	12 cities: Atlanta, Baltimore, Boston, Charlotte, Denver, Dallas, Nashville, Sacramento, San Diego, Montgomery, West Palm Beach Beach, BCD	Brownfield	61	39–81	—
U.S. Conference of Mayors (USCM) 2001	Baltimore and Dallas	Brownfield	—	23–55	36–87[a]
USEPA 2006	Atlantic Station, Atlanta	Brownfield	73[b]	14–52	—
CSI 2009	U.S.	Compact	40	20–60	20–60
NCR 2010	U.S.	Compact	—	5–25	5–25
Ewing et al. 2008	U.S.	Compact	30	20–40	18–36
Nagengast 2011	Minneapolis, Baltimore, Chicago, St. Louis, Pittsburgh, Milwaukee	Brownfield	[c]	[c]	36

[a] Actual number reported is 73%; range was from predevelopment model.

[b] Range is only showing reduction of VOC and NOx.

[c] Nagengast does not directly calculate VKT, but rather focuses on travel time for commuting and concludes that travel time for brownfields is only 3 minutes less than greenfields for all modes: modal shares differed between brownfield and greenfield developments, with transit share higher for brownfields.

This difference implies that characteristics of brownfield developments (i.e., location) should be considered as they can impact travel patterns. The following section examines some of these characteristics.

Brownfield Developments Characteristics and VKT Reductions

As mentioned previously, most urban brownfields are developed as mixed-use or compact developments. Compact development characteristics such as density, diversity, design, and distance to city centers may all be affecting the reduction in VKT, number of trips, and distance per trip. To examine if these characteristics are correlated with the reduction in VKT, using all 16 sites studied in this paper, some of the characteristics associated with compact developments were explored. Results of the correlation analysis show that as distance to center cities increases, VKT increases; as access to transit improves, VKT decreases; and as walkability improves, VKT decreases. Also, brownfield developments show wider and higher range of density associated with less VKT, while greenfield developments show less dense developments (less than 3 HH=acre) with higher VKTs.

Brownfield Developments and Other Social and Economic Factors

Although time, fuel, and environmental cost savings of brownfield developments are important factors when it comes to making decisions to move to urban areas, vacancy rates of the 16 study developments show the average vacancy rate of brownfield developments is higher (9%) than greenfield developments (1%). So the question is if moving to brownfield developments would save about 60% on the cost of fuel and time, why is the vacancy rate higher in urban cores? Factors such as income, age, home value, property taxes, crime rate, and quality of schools are known to be among the most significant factors influencing vacancy rates. Examining the average home values and property taxes, it was concluded that for the 16 study sites examined in this paper, property tax and home values are not the major determining factors. Other factors such as crime rate or quality of schools may affect people's decision more significantly. Details on vacancy rates, home values, and property taxes may be found in the Appendix.

Table 7. Brownfield Site Travel Time Comparisons with National Averages

Study	Home-based work (min)	Home-based nonwork (min)
This study	12	19
NHTS 2009 (national average)	24	18
U.S. Census Bureau 2000 (national average)	26	—

Conclusions

This study has estimated and compared VKTs and their resulting costs of time, fuel, and emissions for eight brownfield and eight greenfield sites in Baltimore, Chicago, Minneapolis, and Pittsburgh, showing that residential brownfields generate significant VKT reduction and cost savings. Brownfield developments studies in this paper on average result in about $2,900 cost savings per household ($2,400/HH from time and fuel savings and $450 from the external environmental cost savings). These estimates can be used in benefit-cost studies to assess the benefits of travel reduction through land use changes and specifically brownfield developments. Comparing the cost savings from travel reductions with the initial cleanup cost, new development densities and the cost of remediation are important in choosing the optimal brownfield site. This study should help policymakers and public agencies involved in the process of brownfield developments make efforts in selecting the sites that ensure the best solution given the amount of remediation needed and the proximity to services such as transit. The study further should encourage policymakers to incentivize the selected brownfield sites by providing remediation funding to the developers/landowners for the environmental benefits of the society. In the process, those who choose to live in the correctly selected and developed brownfield sites (those with close proximity to services and at a higher density) incur annual time and fuel cost savings that can improve other aspects of their lives.

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Supplemental Data

Supplemental information includes travel demand model specific to each city, freeway and arterial kilometer allocation, remediation strategies, APEEP model and its values, correlation analysis: brownfield development characteristics and VKT, vacancy rates, home values and property taxes, Fig. S1, and Table S1, which are available online in the ASCE Library (www.ascelibrary.org).

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