Childhood Lead Poisoning in St. Louis City
System Dynamics Simulation Model Brief
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Executive Summary
The *Childhood Lead Poisoning in St. Louis City* simulation model was developed to explore the problem of lead exposure among young children in the City of St. Louis. Despite significant progress in reducing childhood lead poisoning over the last two decades, rates in St. Louis consistently exceed state and national averages. In 2017, 1.5% of children screened were found to have a blood lead level exceeding 10 µg/dL, a decline from 13.6% of children screened in 2003. However, when measured at the Centers for Disease Control and Prevention's revised reference level for lead poisoning of 5 µg/dL, the overall rate jumps to 6.8% of children screened in 2017. Furthermore, African American children in St. Louis City are 2.4 times more likely than white children to have elevated blood lead levels.

The final model simulates the influence of blood lead testing, follow-up treatment, and home lead remediation on the rate of lead poisoning among children ages 0 to 6 years in St. Louis City. The model simulates how children move through the states of being susceptible, exposed, diagnosed, and recovered, and how they may become re-exposed. Data were drawn from the Missouri Department of Health & Senior Services (DHSS) Environmental Public Health Tracking (EPHT) database query tool, as well as reports from the City of St. Louis Department of Health and other sources. This model aims to provide a basic framework for the factors that affect childhood lead exposure, and to provide ideas for future research.

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Background and Context
Childhood lead poisoning is a serious environmental health issue. It is associated with learning disabilities, neurobehavioral conditions like attention-deficit/hyperactivity disorder, delayed growth and development, and aggressive behavior into adolescence and young adulthood. Infants and young children are especially susceptible to lead exposure, as their developing nervous systems are highly vulnerable to metal toxicity, and their gastrointestinal tracts more easily absorb lead, particularly if the child is iron deficient. While treatment for acute lead poisoning can eliminate it from the blood, the developmental and neurological effects can be permanent. At extreme levels (~100 µg/dL), lead poisoning can result in swelling of the brain, and even death.

In the United States, the primary risk factor for lead poisoning is living or attending school or childcare in buildings built before 1978, when lead-based paint was banned. In St. Louis City, 88.6% of housing units were built before 1980, making the entire city a high-risk area. The Missouri Department of Health & Senior Services (DHSS) has therefore classified the City of St. Louis as a Universal Testing Area, requiring that all children under age 6 living in the city must have their blood tested annually for lead, among other provisions. However, screening rates have declined from a high of 56.4% in 2009 to 44.4% in 2017.

While children living anywhere in the city are at risk, the legacy of residential segregation policies has concentrated African American, low-income families in neighborhoods with higher proportions of older, poorly maintained housing, placing children in these families at disproportionate risk of lead exposure. African American children in St. Louis are 2.4 times more likely than white children to have elevated blood lead levels, accounting for over 70% of all lead poisoning cases. Furthermore, as the city accelerates the demolition of vacant buildings, children living on the same block as one or more demolitions are at an increased risk of elevated blood lead, due to exposure to lead dust.

The City of St. Louis Department of Health offers free blood lead testing and case management services by a public health nurse, in accordance with DHSS guidelines. The city's Building Division works with the Department of Health to operate a Lead Abatement Program, to identify and remove (remediate) lead hazards from residences of exposed children. All laboratories are required to report blood lead test results to DHSS or the City of St. Louis Department of Health. Aggregate data are publicly available through the Missouri Environment Public Health Tracking (EPHT) online portal.

Model Overview

The purpose of our model is to illustrate how children under age 6 are exposed to lead through housing-based risk factors, and how rates of screening, treatment, and re-exposure are part of a feedback system that determines lead poisoning rates. We recognize there are several additional variables that influence lead poisoning that are not included in our model, including the demolition of vacant homes, the role of pediatricians, parents' perception of risk, trust in city departments and inspectors, housing discrimination, etc. Nonetheless, we hope this basic simulation model can serve to test the impact of certain interventions.

The model uses the current CDC reference level of 5 µg/dL as the definition of lead poisoning, although DHSS continues to use 10 µg/dL in its guidelines. The start year is 2014, when 9.2% (1,120) of children screened were found to have elevated blood lead levels. Data from the EPHT portal are used for 2014 to 2017, and the model simulates trends for the next nine years until 2026. The total initial susceptible population in 2014 was 24,088 children in the 0-6 age range, and the birth rate was 4,320 children per year. We estimate rates of aging out of the eligible range at each stage of the system. Since the average screening rate in 2014 was 48.6% and 1,120 children were diagnosed with elevated blood lead levels, we estimate that approximately twice that number would actually be exposed. We therefore set the initial value of exposed children at 2,400, or 10% of the total initial population.

Of those exposed children who were screened and diagnosed with lead poisoning, it was not possible to find data on the proportion who were successfully treated and recovered. For purposes of this simulation, we set the initial value of recovered children at 560, about half of the number initially diagnosed with lead poisoning. We also do not have data on the proportion of children who are re-exposed to lead after they have been treated, if no home lead remediation is conducted, so an initial rate of 50% was estimated.

The capacity of the City of St. Louis to provide screening services and follow-up treatment is limited by available funding, personnel, service costs, and other resources like training and equipment. Based on Department of Health data, we estimate the initial screening capacity at 15,000 children per year, and the initial treatment capacity at 1,200 children per year. In our model, the ratios of children who are in need of screening or treatment to the actual capacity for such services influence the rates of diagnosis and treatment. Similarly, home lead remediation capacity is a function of multiple factors. Based on reports about the city's Lead Remediation Fund, we estimate the initial capacity at 480 homes per year, or a rate of 3% of the estimated 16,480 homes with lead in which children under age 6 reside.

Scenario Testing
We identified and analyzed four policies to determine the impacts on the number of children who are diagnosed with lead poisoning.

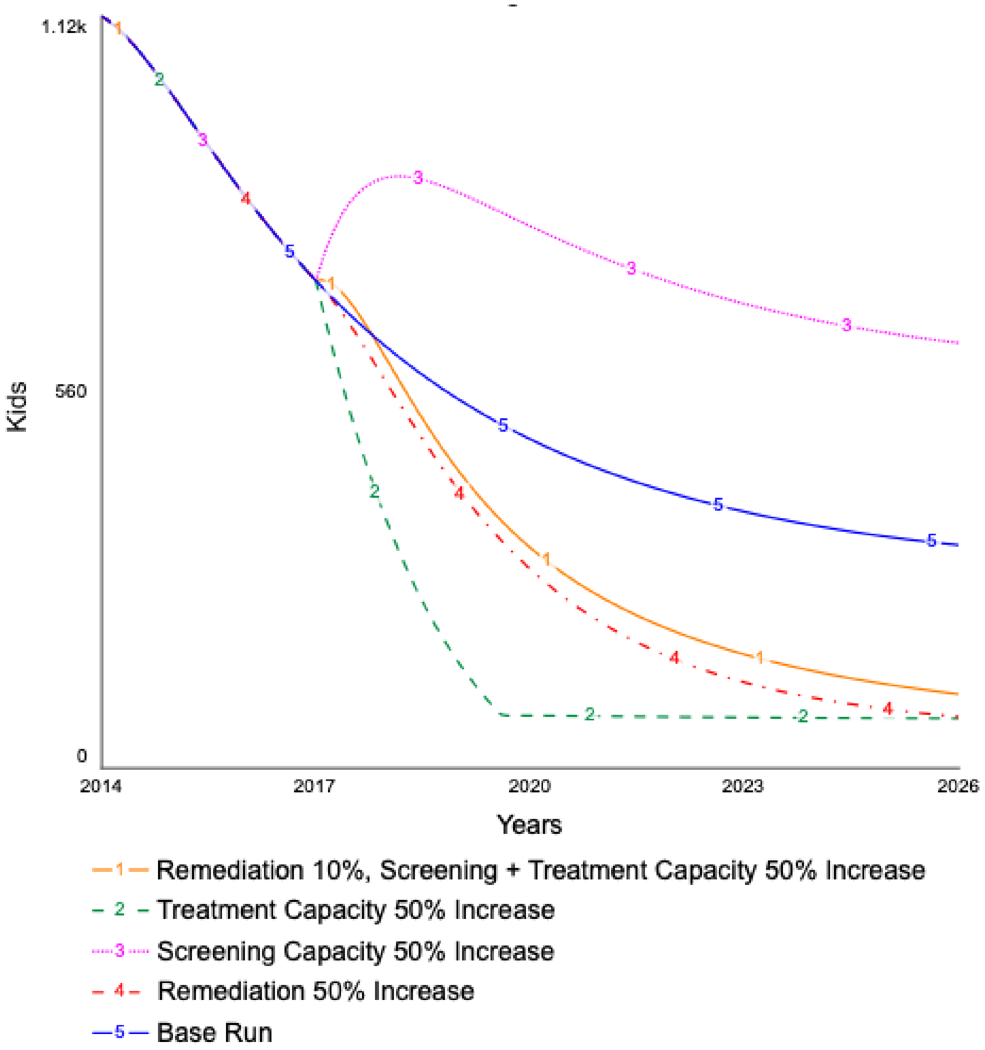
1. *Increasing the screening capacity.* We simulated the impact of increasing screening capacity by 50%, with all other parameters remaining stable.
2. *Increasing the treatment capacity following an elevated blood lead diagnosis.* We simulated the impact of increasing treatment capacity by 50%, with all other parameters remaining stable. Since treatment is currently triggered at 10 µg/dL, this scenario simulates the impact of lowering the DHSS guidelines to the CDC reference level of 5 µg/dL, to capture all children with elevated blood lead.
3. *Increasing the rate of home lead remediation*. We simulated the impact of increasing the rate of home lead remediation by the City's Building Division by 50%. It is important to point out that primary prevention of lead poisoning is essential to avoid irreversible, permanent health effects. Waiting to remediate until a child has elevated blood lead levels is, in a sense, already too late. Our model assumes that remediating the home of a child with lead poisoning also has an impact on new exposures, but it does not separate the impact of conducting home lead inspections and remediating lead hazards proactively.
4. *Combination of interventions.* Knowing that the cost of home lead remediation may be prohibitive, but that increasing screening and treatment capacity would require an increased response, we simulate the impact of increasing home lead remediation rates by 10%, and screening and treatment capacity by 50% each.

Results
All policies were simulated to begin in 2017, when there were 726 children diagnosed with lead poisoning. Figure 1 shows the number of children who would be diagnosed with lead poisoning over time under each of the indicated policies, according to the model.

1. With no changes to the current system (line 5), the number of children diagnosed with lead poisoning would continue to decline to 490 in 2020 and 332 in 2026.
2. Increasing the treatment capacity alone by 50% (line 2) would result in a steep initial decline to 78 children diagnosed with lead poisoning in 2020, followed by a leveling off, to 74 children in 2026.
3. Increasing the screening capacity alone by 50% (line 3) would result in an initial steep increase to 807 children diagnosed with lead poisoning in 2020, followed by a gradual decline, to 633 children in 2026. Without follow-up treatment and home lead remediation services, the number of children diagnosed with lead poisoning continues to exceed that in the base run (line 5).
4. Increasing the rate of home lead remediation alone by 50% (line 4) would result in a substantial decline to 296 children diagnosed with lead poisoning in 2020, down to 76 children in 2026.
5. The combination of increasing home remediation rate by 10%, treatment capacity by 50%, and screening capacity by 50% would closely resemble remediation alone (line 4),

with 328 children diagnosed with lead poisoning in 2020 and 110 in 2026. From 2017 to 2018, the number of diagnosed children is higher than the base run (line 5), because more people are screened and diagnosed. Thereafter, the effects of treatment and remediation are felt, and 66% less children are diagnosed by 2026 compared to the base run.

Figure 1. Impact of Policies on Number of Children Diagnosed with Lead Poisoning



Model Based Policy Implications
Although a 50% increase in the rate of home lead remediation is effective in reducing the lead poisoning rate, the low current rate of 3% per year suggests such a large leap would be unlikely. Simply increasing the screening capacity is also not recommended, as this increases the number of children diagnosed with lead poisoning with no commensurate increase in resources to treat them. It is important to note that while increasing treatment capacity alone results in the greatest initial decline in lead poisoning diagnoses, that is partly because the capacity for screening remains the same. For the policy to be equitable, a decline in diagnoses should not be accomplished by way of constraining access to screening.

The combination of interventions seems to be the most effective and equitable policy, as it would expend screening services to benefit more children, and at the same time provide children with elevated blood lead levels with clinical treatment to help them recover, and home lead remediation to prevent future exposure. It is notable that only a 10% increase in home lead remediation would have the noted effect.

Limitations and Next Steps

Our model shows the basic structural system of childhood lead poisoning in St. Louis City, but does not represent the racial disparities. As a next step, we recommend simulating the model separately for African American and white children to show the existing disparities, and to explore how different policy interventions may have differential influences. This would help us to identify the right combination of policies to reduce overall childhood lead poisoning rates while also reducing racial disparities. Sensitivity tests are also recommended here to test the influence of different variables on the lead poisoning rate.

Our model does not fully account for the branching logic of screening protocols. For example, children are required to be screened annually between the ages of 0 and 6 years, but under certain conditions, should be screened every 6 months; and, in the case of having elevated blood lead levels, may require even more frequent screening. In our model, we use an aggregate average annual screening rate. In a future model, it may be worthwhile to create a co-flow structure to show how children move along different pathways of the protocol. It may also be important to simulate children at different ages, as the data indicate children are less likely to be screened according to protocol after they reach 2 years of age.

Our model does not fully account for the branching logic of treatment protocols. Depending on the exact blood lead level, different follow-up interventions are required, ranging from parental education and re-screening (for 10-19 µg/dL), to physician follow-up for additional lab tests and x-rays along with home inspection and remediation (for 20-44 µg/dL), to oral chelation therapy (for 45-69 µg/dL), to hospitalization and intravenous chelation (above 70 µg/dL). In our model, we use an average treatment rate, and a single outflow to represent successful treatment. A future model could simulate different numbers of children at each level of poisoning, as rates (and costs) of follow-up may differ in meaningful ways.

Lastly, the model was calibrated with several assumptions regarding the rates at which children age out of the eligible range at each stage of the system, which may affect the accuracy of the model.