CDOT Applied Research and Innovation Branch

Integrating the Mobility Energy Productivity Metric into the CDOT Statewide Model

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16. Abstract
The Mobility Energy Productivity (MEP) metric measures the quality of mobility at a specific location and can be used to evaluate how changes to transportation systems impact the mobility of that location over time, such as through infrastructure investments. The objective of this study is to demonstrate integration of the MEP metric into CDOT's transportation planning process by leveraging data from their statewide travel demand model. We evaluate the MEP metric in 2015 as well as 2030 baselines and projected impacts in 2030 for two different regions in Colorado under multiple scenarios across multiple modes (driving, walking, biking, and transit). It was found that increasing development (increasing population density, jobs, and opportunities) had a significant impact on MEP, independent of any specific alternatives. For drive mode, there was a trade-off of increasing congestion on the road network and increasing job and opportunity access. Impacts to bike, walk, and transit MEP were also demonstrated in both regions. This report shows how MEP can be used as a tool to support evaluating the impacts of various transportation projects across the state. With projections of significant growth across the state of Colorado, access to the increasing opportunities and jobs will be important to understand through the context of energy efficiency. MEP could support future project evaluation and decision-making by enabling the unique and important dimension of energy-efficient accessibility of a transportation system.

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The alternatives evaluated in this report are solely for demonstrating MEP integration with CDOT modeling and data. These alternatives evaluated do not necessarily represent any actual changes being considered by CDOT. The results presented in this report are solely for demonstrating MEP integration with CDOT modeling and data and are not intended to be used in CDOT decision making.

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Executive Summary

The National Renewable Energy Laboratory developed the Mobility Energy Productivity (MEP) metric as a tool to quantify energy-efficient access at a given location or across a region. MEP can be used to test how various technological advancements, transportation policies, and infrastructure investments could impact energy-efficient access. MEP considers the available modes in a region (e.g., walking, biking, driving, transit) and the trade-offs of their time, energy, and cost intensity when connecting travelers to opportunities and jobs. This study demonstrates how the MEP metric could be integrated with the Colorado Department of Transportation's (CDOT's) statewide travel demand model.

The time periods considered for this analysis were 2015 and 2030. Data integration from CDOT's travel demand model (TDM) included ingesting and processing statewide data on population, land use, and employment for both 2015 and 2030 (forecast year). The TDM network was processed for use with MEP. Modeled morning peak vehicle speeds were leveraged for MEP calculations in all scenarios. To support more granular assessment of bike and walk modes, OpenStreetMap network data were used to estimate biking and walking accessibility. Impacts to transit were also assessed by integrating transit service changes from the TDM using the General Transit Feed Specification (GTFS) format.

Two different study regions were selected for demonstrative analysis: (1) a 5-mile radius surrounding the I-270 corridor in northeast Denver, Colorado, with a MEP resolution of 250 m^2 to focus on impacts closest to the area of changes at a finer resolution; and (2) the North Front Range Metropolitan Planning Organization (NFRMPO) boundary with a MEP resolution of 1 km^2 to focus on a larger study area encompassing multiple cities across a large planning area. In addition to 2015 and 2030 baseline scenarios for each study region, specific alternatives in 2030 were also considered in the I-270 study region for driving, walking, and biking. Alternatives were modeled in MEP to reflect changes in the I-270 corridor that would impact the different modes. For the drive mode, two additional alternatives were considered given an increase in projected congestion: (1) adding one extra general-purpose lane on the corridor in each direction; and (2) adding one extra managed lane on the corridor that is tolled. For the walk and bike mode, one additional alternative was considered, which added bike and walk paths to increase the network connectivity near an interchange on the I-270 corridor. Lastly, two additional alternatives in 2030 were also considered for the transit mode in both study regions: a greenhouse gas (GHG) baseline, and a GHG compliance scenario. While no specific scenarios were considered for the NFRMPO study region, over MEP trends were evaluated for 2015 and 2030 baselines.

It was found that increasing development (increasing population density, jobs, and opportunities) had a significant impact on MEP, independent of any specific alternatives. For drive mode, there was a trade-off of increasing congestion on the road network and increasing job and opportunity access that resulted in a 2.1% increase in drive MEP in the I-270 study region. When considering alternative scenarios for driving in the I-270 region, adding a general-purpose lane gave an additional 0.5% increase in drive MEP over the baseline, and adding a managed (tolled) lane gave between 0% and 1.3% additional benefit over the baseline. Higher benefit to drive MEP occurs when travelers using the toll lane have a higher value of travel time and amortize costs of tolls. NFRMPO study region saw a 0.55% increase in drive MEP from 2015 to 2030 with the

small improvement resulting from a tradeoff between congestion and land use impacts in the study region. While transit MEP in the NFRMPO also saw a slight improvement from 2015 to 2030, walk and bike MEPs saw a decrease over this same time period. Further exploration revealed this is a result of a spatial disconnect between walk/bike MEP access improvements in the study region and the population growth over that time period.

The results of this study show that MEP can be used as tool to support evaluating the impacts of various transportation projects across the state. Additionally, use of MEP with statewide projections of growth indicates there is value in understanding how future development (increasing population, jobs, opportunities, and congestion) will impact energy-efficient access for Coloradans; in both the I-270 and NFRMPO study regions, increasing development alone had significant impacts on MEP. Increases to bike and walk MEP in this analysis were small due to small-scale changes considered, but significant potential exists for increasing job and development density to have strong positive impacts on public and active transit. To evaluate this potential to the fullest, future travel demand modeling and mobility planning should consider more comprehensive and detailed bicycle and pedestrian options to understand holistic potential to improve energy-efficient access. As the state of Colorado grows, access to the increasing opportunities and jobs will be an important metric to understand how future transportation planning can prioritize efficient, sustainable, and equitable access. MEP could support future project evaluation and decision-making by enabling the unique and important dimension of energy-efficient accessibility of a transportation system.

1. Introduction

Aspiring smart cities are wrestling with questions such as: How does mobility impact a person's quality of life? Would people make different travel choices if they were presented with better information about their mobility options? Would businesses make different location decisions if they could assess the quality of mobility in that area? The ability to quantify the quality of mobility at a given location is the first step toward answering these questions. To address this issue, an interdisciplinary team at the National Renewable Energy Laboratory (NREL) has developed the Mobility Energy Productivity (MEP) metric.

The MEP metric provides an avenue to not only measure the quality of mobility at a specific location in its current configuration, but also to test how various technological advances (e.g., connected and automated vehicles, plug-in electric vehicles, shared mobility) and infrastructure investments (e.g., building an additional highway lane, constructing a new shopping mall, implementing a transit-oriented development) impact the mobility of that location over time. The objective of this study is to integrate the MEP metric calculation into the Colorado Department of Transportation's (CDOT's) statewide travel demand model (TDM). Through this study, NREL researchers can demonstrate how MEP can be leveraged to evaluate the impacts of freeway, bike/pedestrian, and transit infrastructure enhancements in the state.

2. Methods and Data

2.1 MEP Overview

MEP is a score of energy-efficient access; it quantifies how well connected a place is and discounts accessible jobs and opportunities by the energy, cost, and time required to reach them. MEP evaluates multiple modes and access to many types of opportunities (food, health care, education, recreation, and retail) and jobs. A location with a zero MEP score has zero access, which means there are no mobility options (no transportation network) or no opportunities or jobs accessible in a reasonable amount of time (usually up to 40 minutes of travel). A total (overall) MEP score adds up the energy-efficient access by all modes to all opportunities and jobs. This total (overall) MEP score can be broken down to show the energy-efficient access to jobs and opportunities by a specific mode, or to show access by all modes to a specific type of opportunity or to jobs. MEP scores can also be broken down to show access to a specific type of opportunity or to jobs by a specific mode. These types of breakdowns are shown in Figure 1. If one mode has a lower score than another, this indicates that the mode provides less access to opportunities and jobs when accounting for the energy, time, and cost needed to access them with that mode.

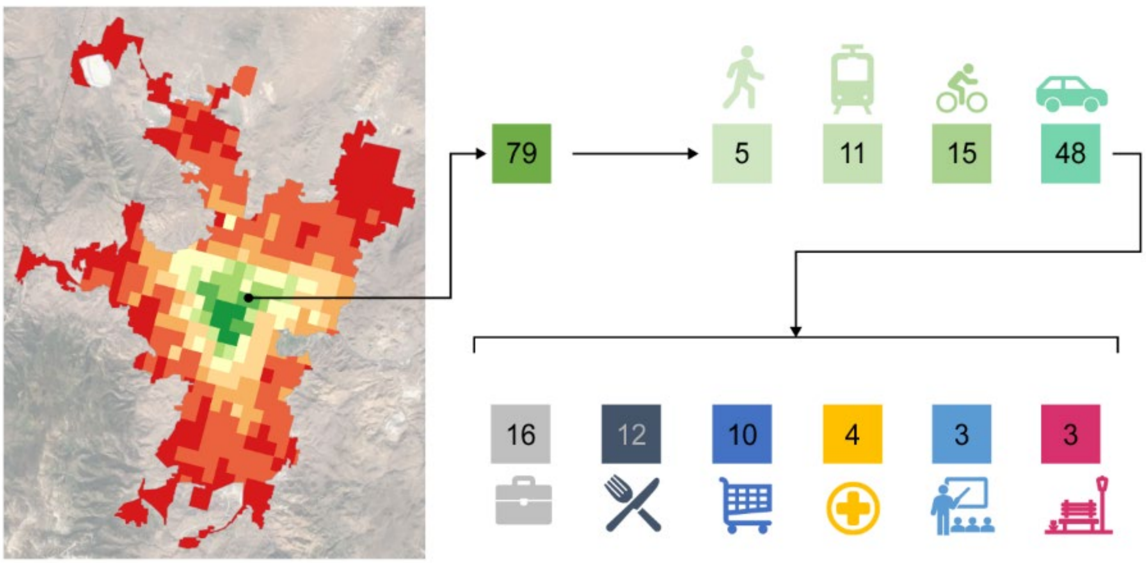

Figure 1. Illustrated MEP score breakdown by modes and activities in Reno, Nevada.

2.1.1 MEP Data Requirements

MEP needs various data sources to perform a calculation:

- Road network: Roadways, bike lanes, sidewalks, paths, etc.; travel speeds (e.g., probes). *Sources*: Third-party data; OpenStreetMap (OSM); travel models.
- Transit network: Generalized Transit Feed Specification data. *Sources*: Provided by transit agency or created from stop/route/schedule data.
- Land use/opportunities: Available opportunities to access (e.g., schools, restaurants). *Sources*: Third-party data; OSM.
- Jobs and population: Where people live; where jobs are. *Sources*: Census or future modeling projections.
- Cost and energy by mode: Average cost per passenger-mile traveled ($/PMT) and energy per passenger-mile traveled (kWh/PMT) for each mode. *Sources*: Various, including Transportation Energy Data Book, modeling, and literature.
- Activity engagement frequencies: Proportion of trips made to different types of opportunities. *Sources:* National Household Travel Survey (NHTS), regional travel surveys, or outputs of TDMs.

2.1.2 MEP Methods and Calculation

Fundamental to calculating MEP is generating isochrones for each desired location in a study region. An isochrone (akin to a watershed) is an area (polygon) formed by a line drawn on a map connecting all the farthest points a traveler can reach from the same origin within a set amount of travel time. To calculate an isochrone, data on travel patterns through the transportation network are needed. For drive, bike, and walk modes, a road network data source is required. Average travel time or speed data for each link on the network is ideal to best represent the actual access on the network. By default, MEP uses isochrones for four travel time thresholds: 10-, 20-, 30-, and 40-minute travel times. These time thresholds can be easily extended or reduced based on the needs of the analysis. For each location, mode, and travel time threshold, a shortest-path algorithm is used (in MEP's case, Dijkstra's algorithm) to create a minimum spanning tree of reachable locations. Figure 2 shows 20-minute walk and 10-minute bike isochrones of a traveler originating from the Colorado State Capitol building in downtown Denver, Colorado.

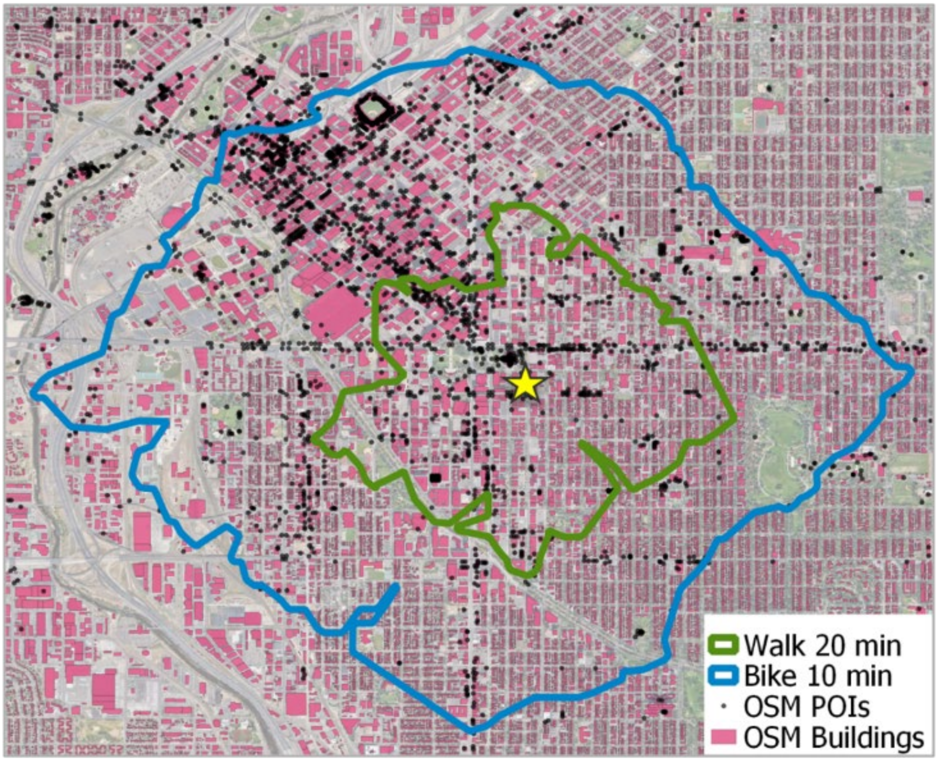

Figure 2. An example of a 20-minute walking isochrone (green) and a 10-minute biking isochrone (blue) originating from the Colorado State Capitol building in downtown Denver, Colorado. Land use is shown from OSM for points of interest (POIs) and buildings (OpenStreetMap 2023).

Isochrones are then used to intersect with a jobs data layer and a land use data layer (or their equivalents) that describe the available opportunities and jobs accessible in a region. In Figure 2, the opportunity space shown is points of interest and buildings data layers from OSM (OpenStreetMap 2023). Ideally, the land use layer will capture all available opportunities in a region across various types of opportunities such as health care, food, retail, education, and recreation (these are the default categories considered in MEP). The total number of opportunities available by category falling within each isochrone is summed up and normalized. Normalization of the available opportunities is done to account for the fact that some categories of opportunities that are often considered essential for a high quality of life are much less prevalent than other categories (e.g., health care opportunities like hospitals and dentist offices are typically much less prevalent than retail or food opportunities). The categories of opportunities used are flexible depending on the granularity available in the land use layer, but the opportunity categories must also align with trip purpose data for the region for all travelers (or a specific cohort of travelers).

A MEP calculation normalizes the frequency of activities engaged based on trip purposes. For example, access to health care opportunities is essential, but many travelers access these much less frequently than other types of opportunities, such as a grocery store. Normalizing the relative frequency of trip types balances MEP's calculation to ensure that frequently engaged types of opportunities (e.g., food opportunities such as grocery stores and restaurants) do not overshadow infrequently engaged opportunity types (e.g., health care opportunities). These data on trip purposes are typically gathered using travel surveys such as the NHTS or through third-party data providers. CDOT did not have trip purpose outputs from their TDM with enough granularity across types, so trip purpose frequencies were derived from the NHTS (Federal Highway Administration 2017).

The final step in computing MEP is discounting the total accessible opportunities by the energy, cost, and time it takes to access them. First, the average energy use and cost expenditure per PMT must be established. For a typical MEP calculation (including the baseline assumptions in this study), data are derived from citable sources. Drive and transit energy consumption are assumed to be 0.9 and 0.65 kWh/PMT (Davis and Boundy 2021), respectively; drive and transit cost are assumed to be \$0.48 and \$0.86/PMT (AAA 2023; Federal Transit Administration 2016), respectively; and bike and walk modes are assumed to have zero energy use and cost. Each of these factors by mode is used in the MEP calculation to discount available opportunities by the energy, time, or cost consumed to reach them. Note that the weighting parameters used in the equation for this step weighs time more heavily such that it has a weaker impact on decaying the value of opportunities, because travelers typically weigh travel decisions based on time constraints first. The MEP formula is specified as:

$$MEP_i = \sum_k \sum_t (o_{ikt} - o_{ik(t-10)}) \cdot e^{U_{ikt}}$$

where MEP_i is the MEP metric at location i across mode(s) k within time thresholds t. This summation can be thought of as a discrete integral of opportunities reachable by available modes over isochrones of increasing size by time threshold t (10, 20, 30, and 40 minutes). For more details on the MEP formulation, see Hou et al. (2019). The overall MEP score for a given location is then measured by considering how many people are enjoying (or suffering from) the quality of mobility at the location. Thus, overall MEP for a region or city is calculated by taking the population-weighted average across the region or city. In the equation, o_{ikt} is the number of benchmark opportunities that can be accessed by mode k within the travel time threshold t from the i^{th} pixel. The weighting is further defined as:

$$U_{ikt} = \alpha e_k + \beta t + \sigma c_k$$

where U_{ikt} is the utility of the opportunity type j that is accessed by mode k with travel time t to the location i; e_k is the energy intensity (kWh/PMT) of mode k; t is travel time; c_k is the cost intensity (\$/PMT) of using transportation mode k; and α, β, and σ are weighing coefficients for energy, time, and cost factors respectively. In this analysis, the default weights for energy, time, and cost decay are used: $\alpha = -0.5$, $\beta = -0.08$, and $\sigma = -0.05$. These weights were established in the initial formulation of MEP by Hou et al. (2019); see this work for a detailed overview of the MEP methodology. The default weight for time access ($\beta = -0.08$) in Hou et al.'s study was derived from Owen and Levinson (2014), and the energy and cost weights were based on the judgment of the authors. These weighting parameters have the effect of more strongly decaying opportunities by the cost and energy intensity of a mode, and less strongly decaying opportunities by the time intensity of a mode (i.e., the average speed of a mode is more impactful to accessibility than the mode's energy or cost intensity). For a detailed impact of weighting parameters on the decay of accessible opportunities, a detailed breakdown of a MEP score calculation for a single location between drive and e-bike modes (starting at the Colorado State Capitol building in downtown Denver, Colorado) is demonstrated in Hoehne et al. (2023). While the default resolution for a MEP analysis is a 1-km^2 pixel, it is straightforward to increase or decrease the granularity of this resolution, as demonstrated in the scenarios considered for this project.

2.2 CDOT Scenarios

Two different project study regions were selected to demonstrate the use of MEP in project evaluations. These two examples were selected to represent differing spatial extents and spatial resolution (i.e., MEP pixels). The I-270 study region focuses on a smaller region immediately surrounding the I-270 highway corridor in northeast Denver (Commerce City), and the North Front Range Metropolitan Planning Organization (NFRMPO) study region focuses on a larger planning region.

2.2.1 I-270 Study Region and Scenarios

CDOT is considering a series of improvements along the I-270 corridor, including adding new lanes, reconfiguring interchanges, improving ramps and pedestrian connections, replacing aging bridges and pavement, and widening shoulders (CDOT 2023c). To demonstrate how MEP could be used in similar projects to access impacts to energy-efficient access, a few of the improvements that have been proposed along this corridor were considered to examine their potential impacts to MEP. The specific improvements considered in this project may not necessarily align with the exact proposed or selected improvements on this corridor, and any results presented in this report are not intended to be used in any CDOT decision-making processes.

The I-270 study region was developed as a 5-mile radius surrounding the corridor to focus on impacts closest to the area of changes. A 250-m^2 resolution for MEP pixels was chosen to assess impacts to MEP in the study region at a smaller scale, as the overall study region is smaller. MEP was leveraged to model the corresponding changes in compatible aspects: (1) modeling the highway lane addition and repurposing through speed changes; (2) modeling toll roads through time and speed changes; and (3) modeling the walk lane addition through network changes.

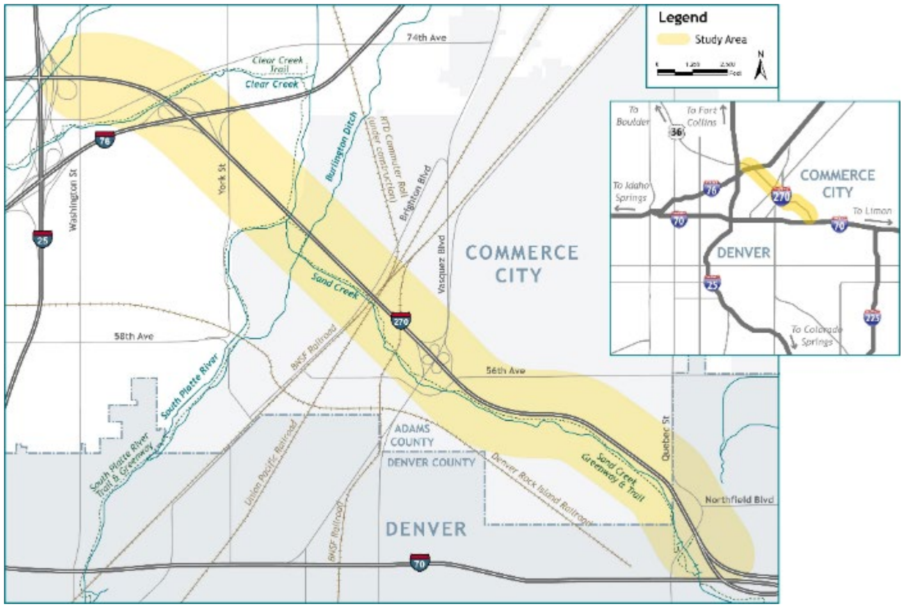

Figure 3. The study area for the proposed changes on I-270. Note: The specific alternatives considered in this report are for demonstrating MEP integration with CDOT modeling and do not necessarily represent the actual changes being considered and are not intended to be used in CDOT decision-making.

For I-270 alternatives impacting the drive MEP, multiple scenarios were considered: a 2015 baseline, a 2030 ("no action") baseline, a 2030 alternative with only one additional general-purpose lane in each direction (three non-tolled lanes in each direction), and an alternative with one managed (tolled lane) in each direction. Table 1 shows the different average speeds across each direction in the I-270 corridor for each of these scenarios. While a MEP calculation considers different routes, it is not able to differentiate between tolled and general-purpose lanes unless these lanes are separate links within the network with distinct speeds and link-level costs (to account for additional optional tolls). To consider tolled vs. non-tolled speeds or travel times, the toll cost needs to be factored in at the link level. This can be done using value of travel time (VOTT) assumptions to convert costs of tolls to time savings (and increased travel speeds). To compare MEP impacts of using the tolled lane vs. the non-tolled lane (when the toll lane is present), we consider two separate sub-scenarios for the 2030 managed lanes scenario.

Table 1. Speed assumptions for I-270 alternative scenarios.

Year	Scenario	Total Lanes in Each Direction	Lanes by Type in Each Direction	Westbound Avg. Speed	Eastbound Avg. Speed
2015	Baseline	2	2 general purpose	32 mph	27 mph
2030	Baseline (no action)	2	2 general purpose	26 mph	20 mph
2030	Add general-purpose lanes	3	3 general purpose	43 mph	50 mph
2030	Add managed lanes	3	2 general purpose	34 mph	44 mph
2030	Add managed lanes	3	1 managed/express	58 mph	58 mph

Toll costs were derived based on data from the *Express Lanes Master Plan* (CDOT 2023a). The use of managed lanes is evaluated based on translating the expected average toll costs for using the entire 7-mile corridor, which came out to approximately $8 during the morning peak period. Since there is typically a range of types of toll users (regular users vs. non-users) and different

VOTT for travelers, the sensitivity of toll costs and VOTT was evaluated under infrequent vs. frequent use (amortized and non-amortized costs) and VOTT range of \$35–\$60/hour. This captures low- and high-VOTT toll users, as well as potential regular vs. infrequent toll users. There were a few different areas with proposed improvements to pedestrian and cycling paths on the corridor. In order to demonstrate how this could be captured with MEP, a section of proposed path additions near I-270 and Vasquez Boulevard was added. Since the network obtained from the CDOT statewide travel model did not contain enough granularity, the MEP team (in consultation with the CDOT team) decided to use the OSM network for bike/pedestrian analysis in the project. Proposed links were added in the 2030 OSM bike and walk network using the JOSM editing tool (JOSM 2023). Figure 4 shows the before and after snapshots at this intersection with the added bike/walk links.

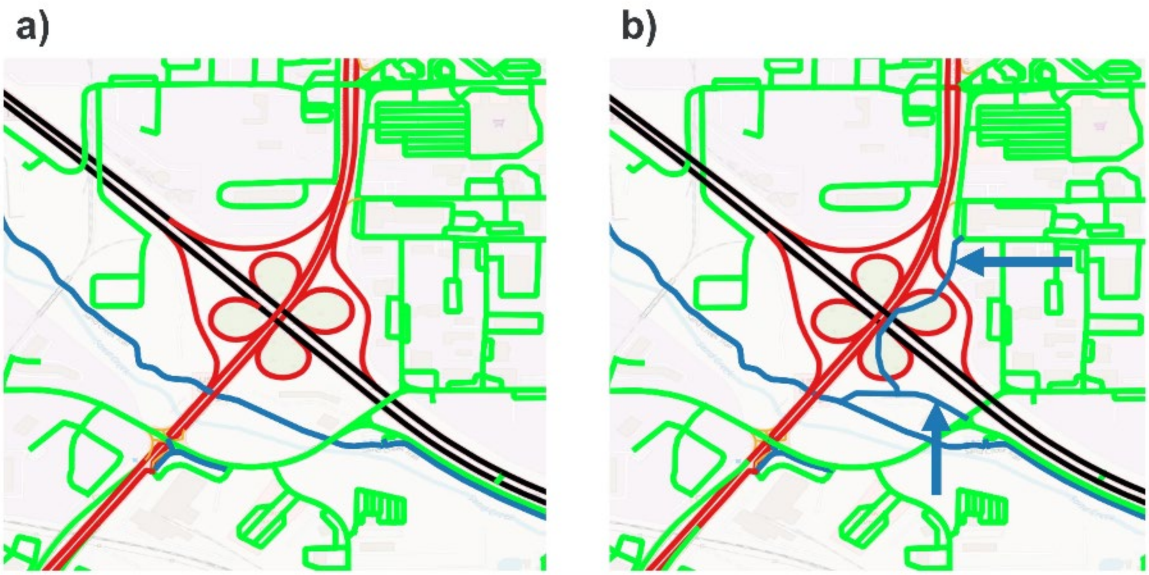

Figure 4. Before (a) and after (b) addition of bike/walk links near Vasquez and I-270.

2.2.2 NFRMPO Study Region

The NFRMPO study region is the entire boundary of the NFRMPO for a different (larger/metropolitan planning organization) perspective. In this region, the default 1-km^2 resolution for MEP pixels was chosen since the region is larger and comparable to the size of a metropolitan region (which is the common spatial unit used for MEP analyses). Figure 5 shows the NFRMPO boundary used as the study region. For this study region, no specific project alternatives were considered. Instead, the results were estimated to show a contrasting location and a differing resolution for MEP to demonstrate the flexibility of scenario formations.

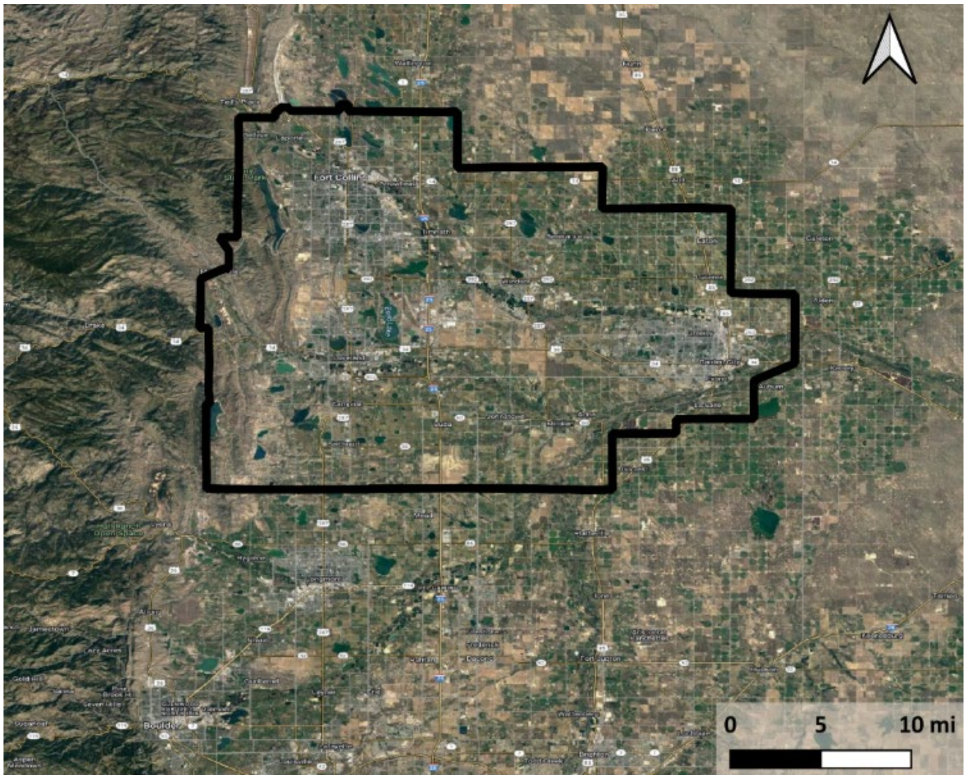

Figure 5. The NFRMPO boundary.

2.3 CDOT Data Integration

CDOT provided several datasets and other information to the NREL team to evaluate MEP integration and demonstrate the impacts of using MEP.

2.3.1 Network Data

The network data was provided by CDOT for 2015 and 2030 baseline (no action) scenarios. A snapshot of the network is shown in Figure 6. The network primarily encompasses major arterials and highways but lacks granularity of capturing some minor arterials, tertiary roads, and local roads. All drive scenarios assumed travel speeds from the morning peak period. On the I-270 southeast-bound direction, a bottleneck between I-76 and Brighton Boulevard resulted in 2015 speeds of 14 mph, which dropped to 9 mph in the 2030 (no action) baseline.

Without minor and local roads being captured, there is a lack of information for determining accurate walk and bike access, as many possible routes are not mapped out. The CDOT TDM models origins and destinations of walk and bike trips, but these trips are not assigned to the sparser roadway network. To account for this and allow for detailed consideration of walking and biking access, walk and bike networks were extracted from OSM data (OpenStreetMap 2023). Raw OSM data of walk and bike links were further processed to be compatible with MEP calculation procedure (to enable shortest-path searches on a routable network).

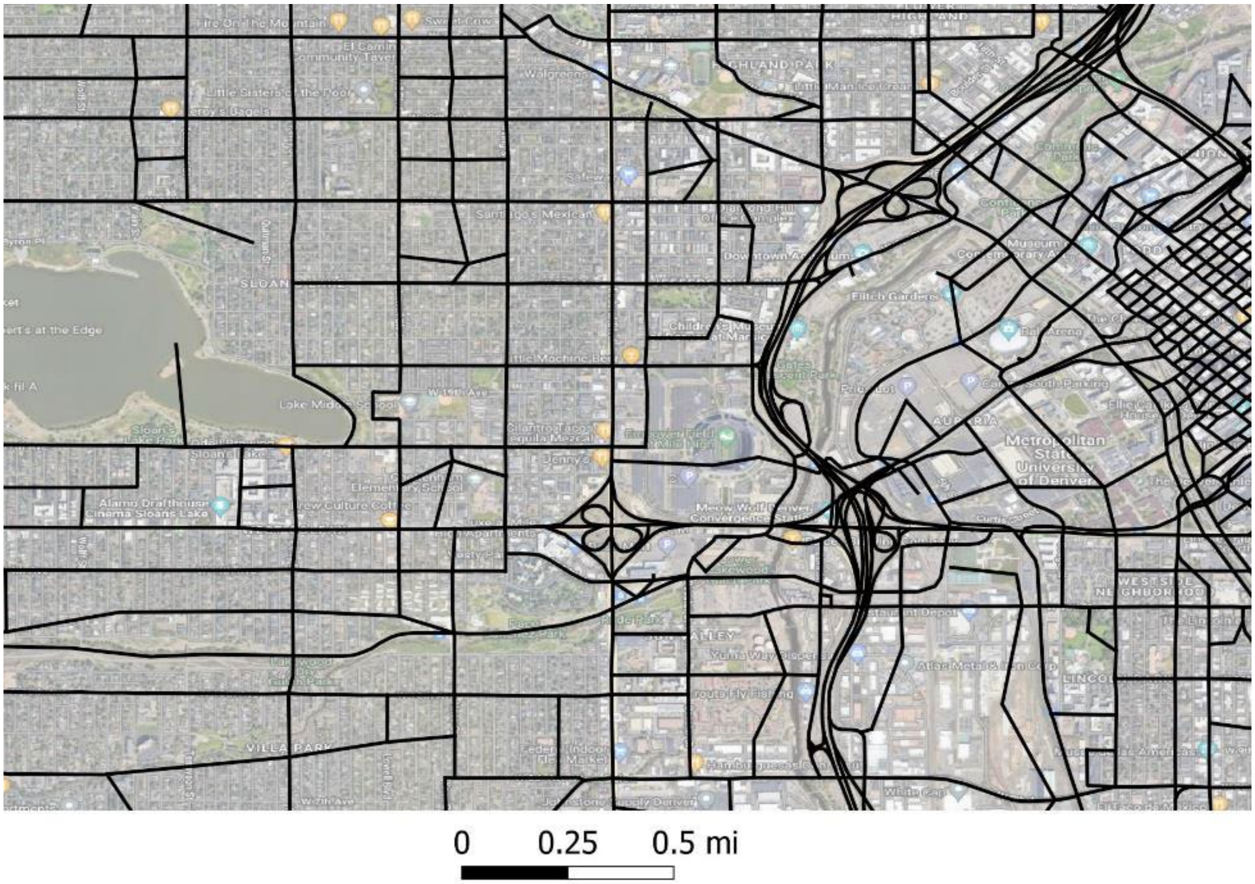

Figure 6. A snapshot of the CDOT TDM network used for the drive MEP.

2.3.2 Opportunity and Employment Data

Opportunity and employment data were obtained from the CDOT statewide TDM for 2015 and 2030. Data from 2015 have information on jobs in the region, but 2030 does not. Analysis revealed that the correlation between jobs and total employment categories was found to be about 0.87, so employment was used as a proxy for jobs. Data from 2015 have 3.16 million employment opportunities and from 2030 have 4.0 million employment opportunities (26% growth in 15 years). A 50-mile buffer around the study region was considered to capture all opportunities that can be feasibly accessed in 40 minutes or less for a trip starting within the study region. For example, a trip could originate at a location adjacent to the I-270 corridor in the study region, and in 40 minutes reach many opportunities outside of the study region such as opportunities and jobs north or south of downtown (e.g., Broomfield, Englewood).

Data were missing for the health care category (no breakdown for "Service" category), so although it is implicitly included in services, we could not differentiate health care opportunities and thus excluded them (and all service-type opportunities). To improve or fix this assumption in the future, the model would need a breakdown of the types of activities with corresponding trip purpose (engagement) frequencies. This way, MEP can be tailored to a specific region and/or a specific set of trip purposes and activity types. For example, this approach can also be used to assess the difference in realized MEP and energy-efficient access across groups with distinct travel behaviors and patterns (e.g., young vs. geriatric populations typically have different travel patterns with trade-offs in access to education vs. job opportunities).

Opportunity type “Production” is excluded (Figure 7) since it could not be mapped to any of the standard MEP categories. To account for potential differences in the relative number of opportunities in the CDOT dataset, as well as to normalize the overall prevalence of opportunity types to each other, activity normalization was used. The restaurant category was used as the reference category. This makes sure opportunities that are less common (e.g., education) are not washed out in valuing access across different types of opportunities.

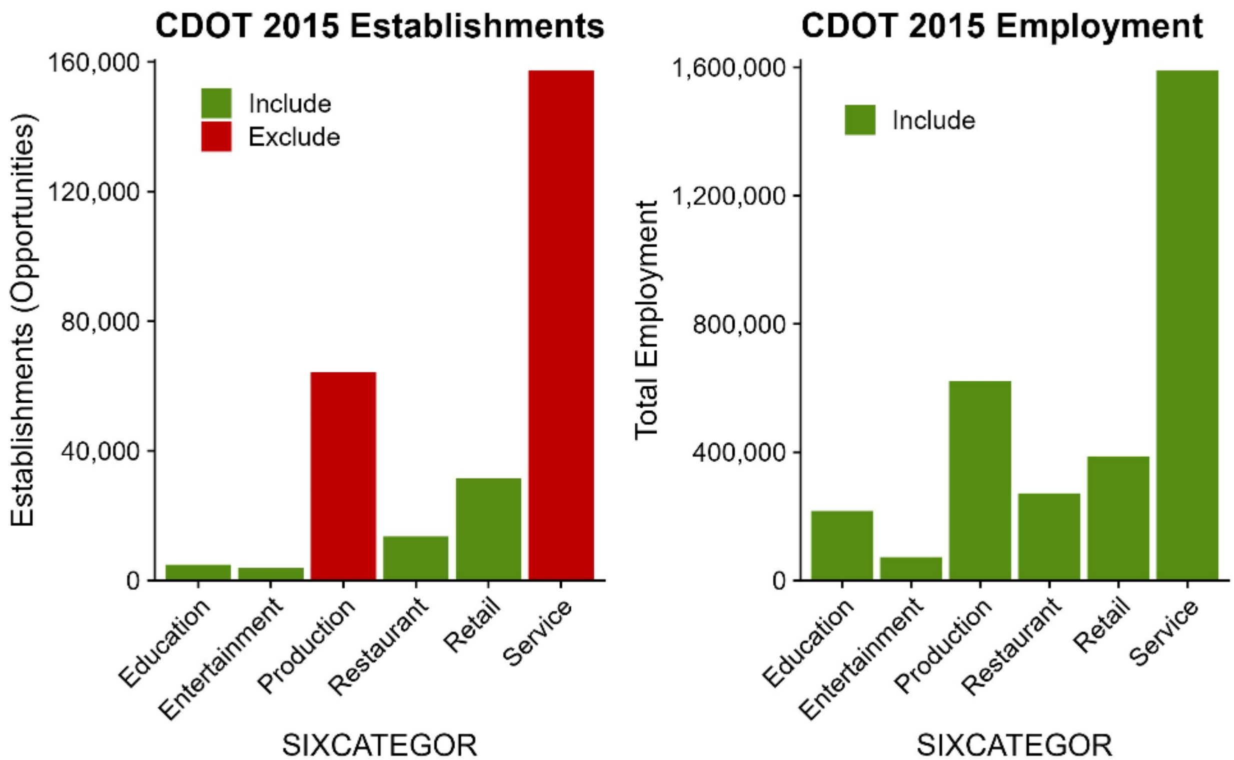

Figure 7. Statewide establishment and employment data used by CDOT TDM integrated into MEP calculations.

2.3.3 Population Data

CDOT provided 2015 and 2030 statewide snapshots of household-level point data (latitude and longitude with population counts). These point-level population data were aggregated to the 250-m^2 MEP pixel resolution for use in population weighting of scores across the study regions. Population data are important for MEP because high-quality access from a location is most valuable where people live.

In converting the provided CDOT population (housing) data, we chose to only include the household entity type “household” and exclude “group quarters.” This was done to avoid inclusion of types of populations that may not traditionally have access to or use the transportation network at all, such as incarcerated populations or populations living in assisted living facilities. In particular, the 2030 housing data had 1,464 people marked in group quarters housing in a collection of parcels with various correctional facilities (including the Denver County Jail and the Denver Women’s Correctional Facility) near Smith Road and Havana Street within the I-270 study region (39.766270, −104.863300). Future analyses with MEP that utilize this type of housing data may consider including group quarters populations on a case-by-case basis or if the data classification is updated to distinguish between various subtypes of group quarters to more easily include and exclude populations that would be eligible or make regular use of the transportation network (e.g., include university students in dormitories and service members in barracks but exclude incarcerated populations and consider excluding assisted living facilities).

Figure 8 shows the projected population growth from 2015 to 2030 at the 250-m^2 MEP grid resolution for the I-270 study region. Most of the projected population growth is concentrated around the central business district (e.g., along Broadway north of Colfax Ave.). On the contrary, there is very little population growth in the immediate vicinity of I-270, as this is a heavily industrial area north of downtown (Commerce City).

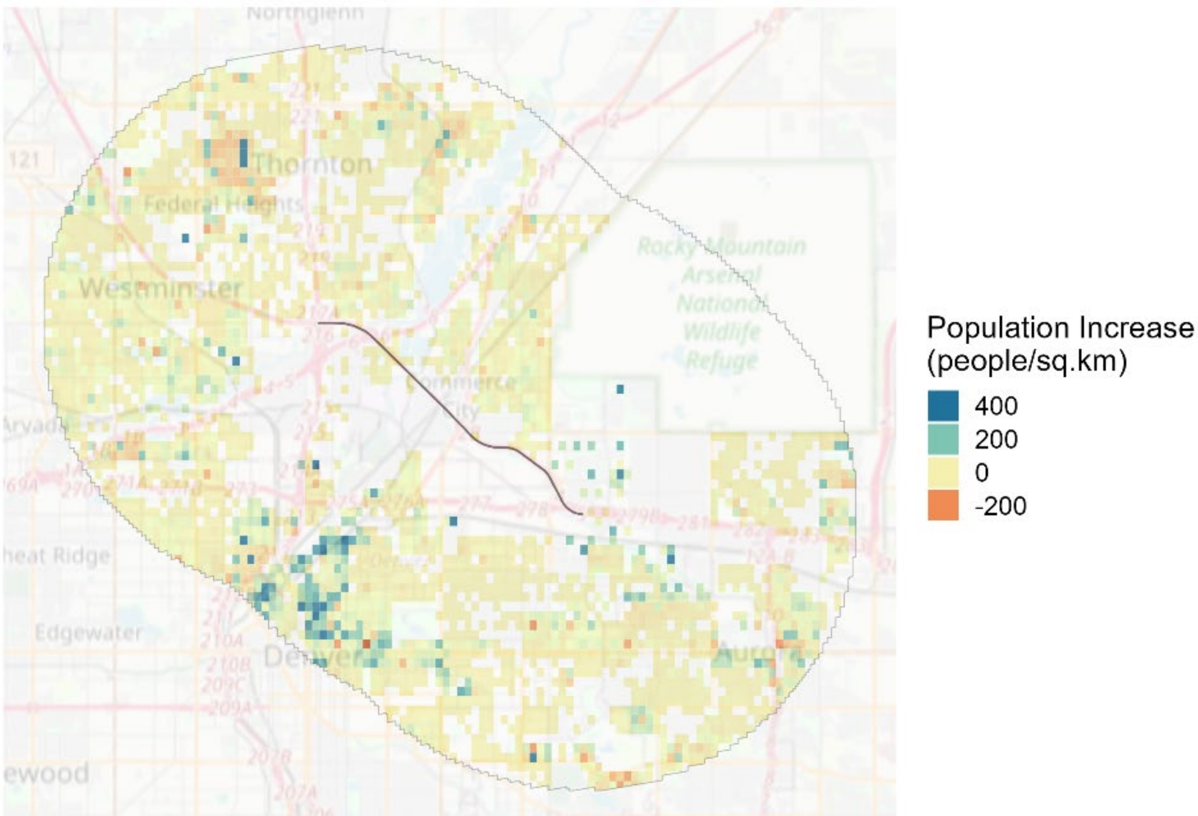

Figure 8. Population growth in the I-270 study region from 2015 to 2030. Areas without coloring (transparent) had no population growth in the time period.

3. Results

3.1 I-270 Scenarios

Three different sets of scenarios were conducted for the I-270 analysis to reveal the changes in MEP for 2030, as well as to explore the impacts of highway lane improvements and walk lane additions.

3.1.1 2015 and 2030 Baselines

The 2030 scenario was conducted to demonstrate the impacts of demographic and network changes on the 2030 network in contrast to the 2015 baseline scenario. The changes include the new road network from the statewide analysis model, new land use patterns (due to development), and projections of changing populations and employment opportunities. Table 2 shows the population-weighted MEP scores for all four modes for the 2015 and 2030 baselines. Figure 9 shows the drive MEP change from 2015 to the 2030 baseline. The 2015 scenario has a drive MEP of 387, while the 2030 scenario has a drive MEP score of 395. The spatial distribution of changes indicates lower scores north and west of the I-270 corridor (primarily Commerce City, with some around Westminster/Arvada) and higher scores south of the corridor (especially around Colfax Ave. between downtown Denver and Aurora). There is a 2.1% increase in the overall drive MEP across the whole area, because of a trade-off between the increased opportunity density and the road network congestion condition.

Table 2. Study regionwide population-weighted MEP scores for each mode in the 2015 and 2030 baselines. Note the 2030 baselines are "no action" scenarios; for transit this is the greenhouse gas (GHG) baseline (no GHG compliance), and for other modes this means no action taken to change the transportation network.

Scenario	Drive MEP	Bike MEP	Walk MEP	Transit MEP
2015 baseline	387	17.9	3.3	19.7
2030 baseline	395	19.7	3.7	20.5
Increase 2015 to 2030	2.1%	11%	12%	4.1%

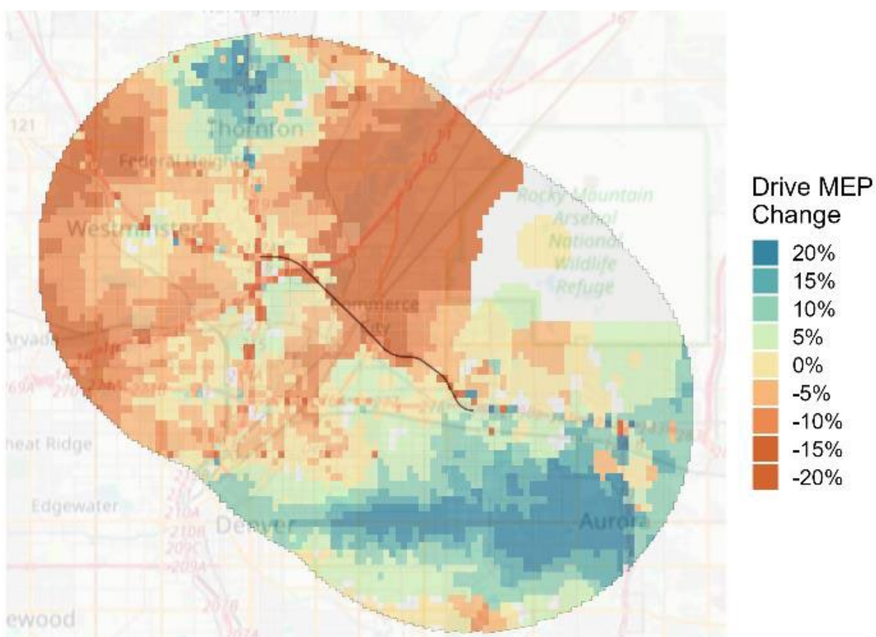

Figure 9. I-270 drive MEP difference from the 2015 baseline to 2030 baseline.

The mixed impacts of opportunities and road network congestion can be separated, as shown in Figure 10. When controlling for the difference between impacts due to network congestion vs. land use and job development, it was found that there was a 16% decrease in drive MEP due to increased network congestion and an 18% increase in drive MEP due to increased land use and jobs development. These trade-offs give a 2.1% net increase in total drive MEP from the 2015 baseline to the 2030 baseline. The increase in employment opportunities is a big driver of these changes, and Figure 11 shows how the jobs MEP has increased in the study region in the baseline. These development and congestion changes also impacted bike and walk MEP, which resulted in a ~12% increase for both walk and bike MEP in 2030 from the 2015 baseline.

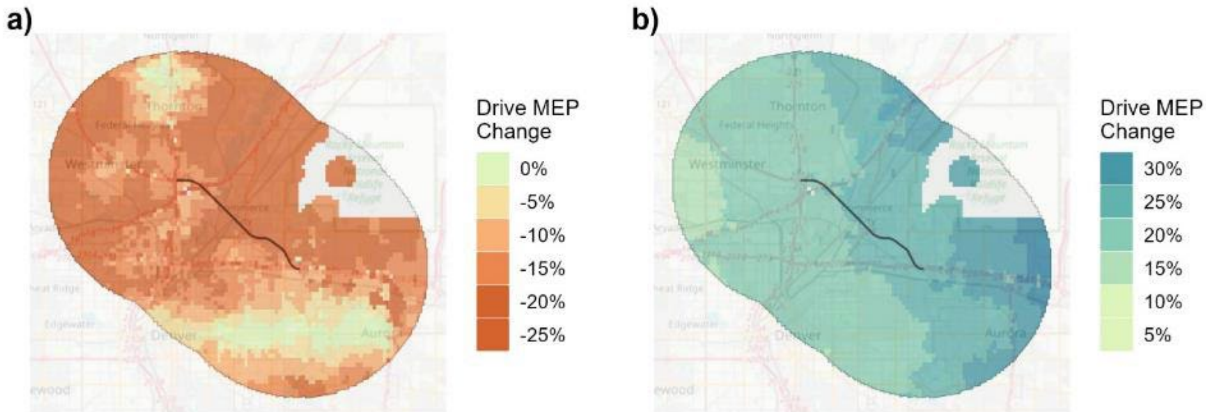

Figure 10. I-270* drive *MEP difference due to* (a) *congestion only and* (b) *land use only. Changes in (a) are due to increased network congestion from 2015 to 2030 while holding land use and jobs static, and changes in (b) are due to increased land use and job development from 2015 to 2030 while holding network congestion static.

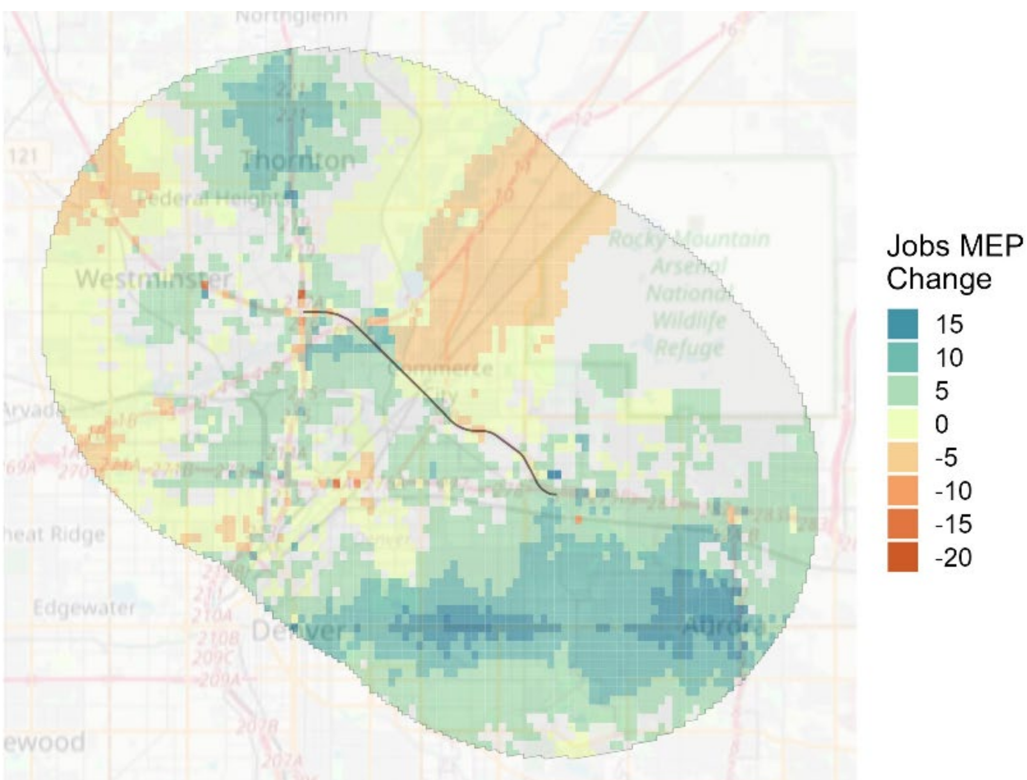

Figure 11. Job MEP change from 2015 to 2030 in the I-270 study region.

3.1.2 Drive MEP Alternatives

Table 3 shows the drive MEP results for both the I-270 alternatives considered and the baselines. To demonstrate the impact of the managed lanes scenario vs. the 2030 baseline (no action), Figure 12 shows the drive MEP increase from the 2030 baseline to the 2030 managed lanes scenario. The concentration of locations (pixels) had increases in drive MEP adjacent to the I-270 corridor, but most other locations had little to no impact. Some locations directly adjacent to the corridor show as much as 25% improvements in drive MEP compared to the baseline. However, most of the study region population lives outside the areas that see significant improvements. As a result, the overall population-weighted improvements from the 2015 baseline range from 2.0% to 3.1% depending on toll cost assumptions. For using the managed lane along the entire corridor with the most conservative assumption (a traveler with low VOTT and non-amortized toll cost), there is no increase over the 2030 (no action) baseline. This makes sense, as many users (especially those with lower VOTT) will opt to not use the tolled lane option under most scenarios. With a more aggressive assumption in line with more regular toll lane use (higher VOTT and amortized toll costs), there is an additional increase in drive MEP in 2030 of 1.1% (from 2.0% in the 2030 baseline to 3.1%). This indicates that the managed lanes scenario provides marginal increases in drive MEP for most users (assuming only more frequent and higher-VOTT travelers use the toll lane regularly). However, there is a slight drop in 2030 of 0.2% (from 2.5% to 2.3%) for travelers who only use general-purpose lanes; the replacement of one general purpose lane with a managed (tolled) lane in the two alternatives reduces the capacity of general-purpose lanes (i.e., three general-purpose lanes vs two general-purpose plus one tolled). Thus, there is a slight reduction in peak-hour travel times (and thus drive MEP) for travelers using the two general-purpose lanes in the "Add managed lanes" alternative compared to three general-purpose lanes alternative.

Table 3. Drive MEP results for all I-270 study region scenarios. The overall drive MEP shown is population weighted (each location's score is weighted by its population). The ranges for the managed lanes scenario incorporate the sentivivty of traveler VOTT and amortized vs. non-amortized toll costs.

Year	Scenario	Drive MEP	% Increase Over Base
2015	Baseline	387.4	-
2030	Baseline (no action)	395.3	2.0%
2030	Add general-purpose lanes only	397.3	2.5%
2030	Add managed lanes: general-purpose lanes only	396.5	2.3%
2030	Add managed lanes: tolled lanes only	395.2–399.3	2.0%–3.1%

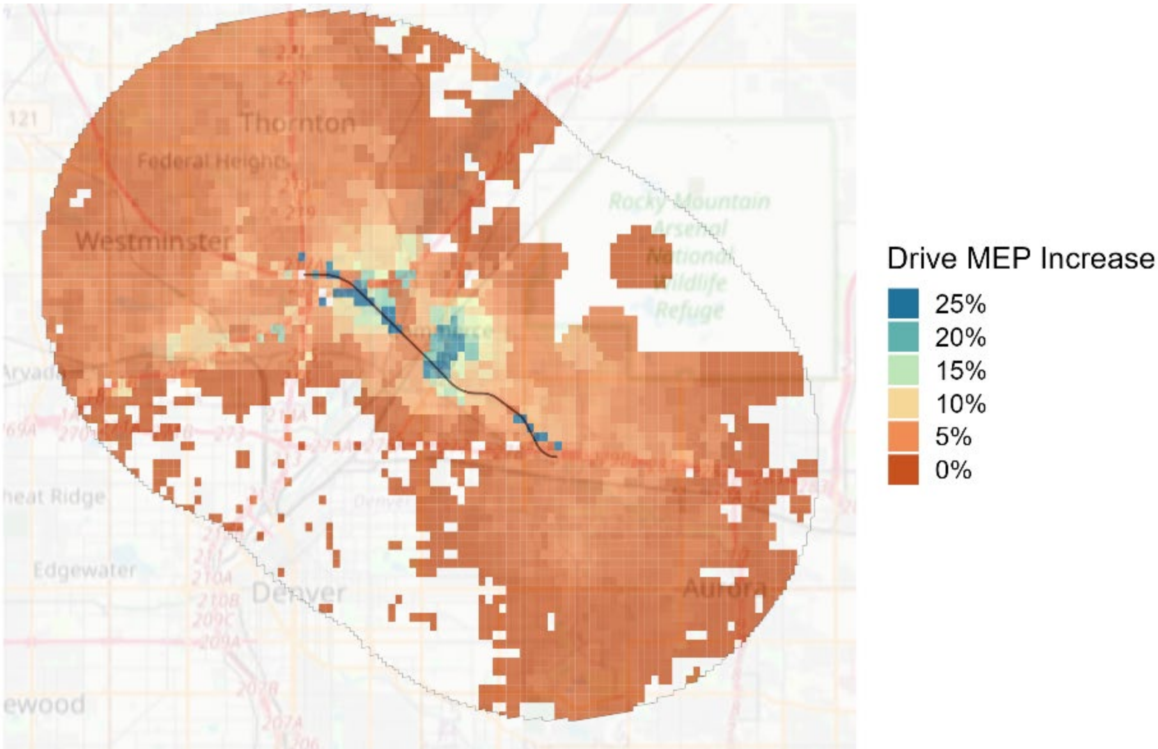

Figure 12. Drive MEP change from the 2030 baseline (no action) to the 2030 managed lanes scenario with the greatest impact on MEP (high VOTT and amortized toll costs).

3.1.3 Transit MEP Alternative

While no specific transit modifications were considered as part of the I-270 project, two 2030 scenarios for transit were considered in the study region to demonstrate how transit MEP could be impacted by future changes in transit service. The 2030 baseline for transit aligns with the "no action" scenario, where minimal changes to service are projected in the future (GHG baseline). The alternative considered for transit assumes transit service changes are made to ensure transportation in the state is compliant with recent GHG Transportation Planning Standard set by the state Transportation Commission (CDOT 2023b). The transit MEP results are displayed in Table 4. Figure 13 shows the transit MEP change from 2015 to the 2030 GHG baseline. In both 2030 scenarios, the Civic Center Station (Colfax and Broadway) sees the highest increase due to expanded transit service at this central station. Most other areas in the study region see limited changes. In 2030, the transit MEP in the GHG baseline is slightly higher than the GHG compliance scenario. However, it should be noted that the energy and cost assumptions were held constant across all scenarios, so they do not fully reflect the impacts of transit enhancements that may reduce emissions (e.g., electrification).

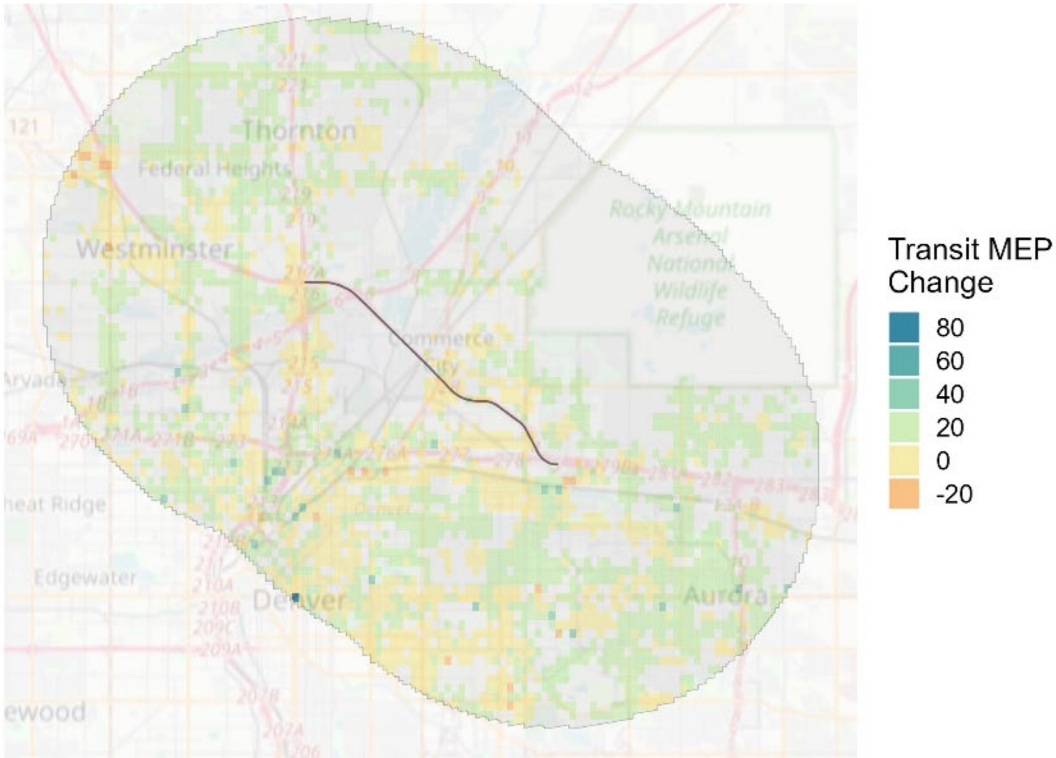

Figure 13. Transit MEP change from 2015 to the 2030 GHG baseline in the I-270 study region.

Table 4. Transit MEP results for the I-270 study region scenarios.

Year	Scenario	Transit MEP (Population-Weighted)	% Increase Over 2015 Base
2015	Baseline	19.7	-
2030	GHG baseline	20.5	4.1%
2030	GHG compliance	20.4	3.6%

3.1.4 Walk/Bike MEP Alternative

An alternative scenario for the I-270 corridor added a few bike/walk paths near Vasquez and I-270 (Sand Creek Trail) to improve connectivity in the area. To investigate the MEP impacts, we focus on the MEP grid cells immediately adjacent to the intersection with improvements. Figure 14 shows locations (grid cells) near the I-270 and Vasquez intersection that impacted walk MEP. Table 5 shows opportunity and job counts for walking for grid cells near the same intersection. The change in the total opportunities and jobs that isochrones can cover shows that both increase in land use and the addition of a walk lane have an impact on access, and there is a greater impact from the land use change from 2015 to 2030 than the addition of paths in 2030. Within the opportunities category, recreational opportunities had the greatest increases, with their access more than doubling for 10-minute walks.

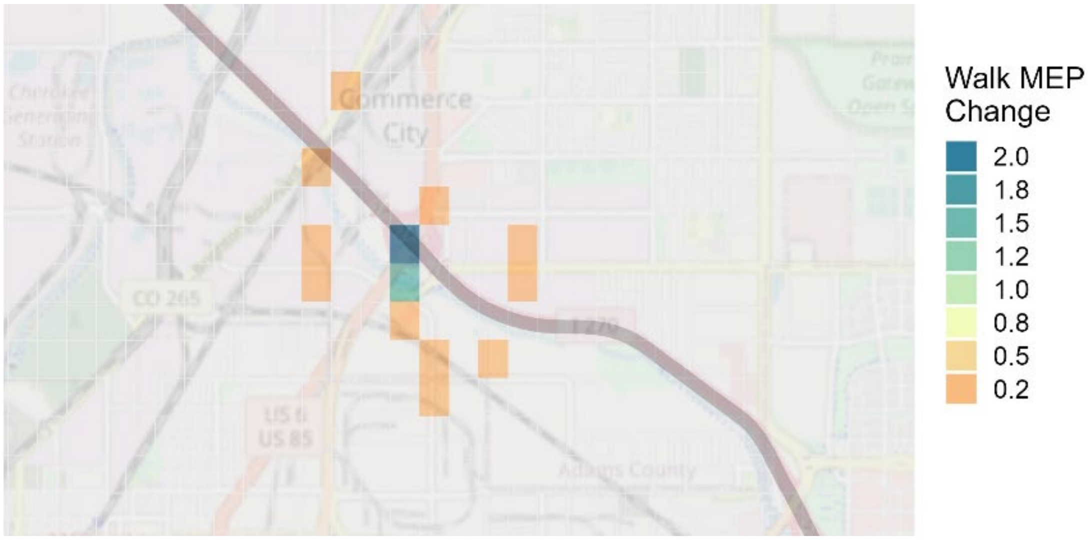

Figure 14. Walk MEP impacts from added bike/walk paths near Vasquez and I-270.

Table 5. Total walk mode opportunity and job counts and the percent increase for locations with impacted MEP near the I-270 and Vasquez intersection. The "2030 paths" scenario represents the scenario with added paths.

Walk Isochrones	Scenario	Opportunities	Jobs	% Increase to Opportunities from 2015	% Increase to Jobs from 2015
10 min	2015 baseline	83	6,592	-	-
10 min	2030 baseline	113	8,138	36%	23%
10 min	2030 paths	129	9,552	55%	45%
20 min	2015 baseline	434	40,556	-	-
20 min	2030 baseline	547	44,128	26%	9%
20 min	2030 paths	600	46,963	38%	16%
30 min	2015 baseline	1,076	112,958	-	-
30 min	2030 baseline	1,334	127,333	24%	13%
30 min	2030 paths	1,379	134,316	28%	19%
40 min	2015 baseline	2,049	234,092	-	-
40 min	2030 baseline	2,521	266,333	23%	14%
40 min	2030 paths	2,670	287,458	30%	23%

To better visualize the change in isochrones, Figure 15 shows the 10-min, 20-min, 30-min, and 40-min isochrones for a grid cell located nearest to the improvements, with (a) demonstrating the isochrone before the path additions and (b) for the case after the path additions.

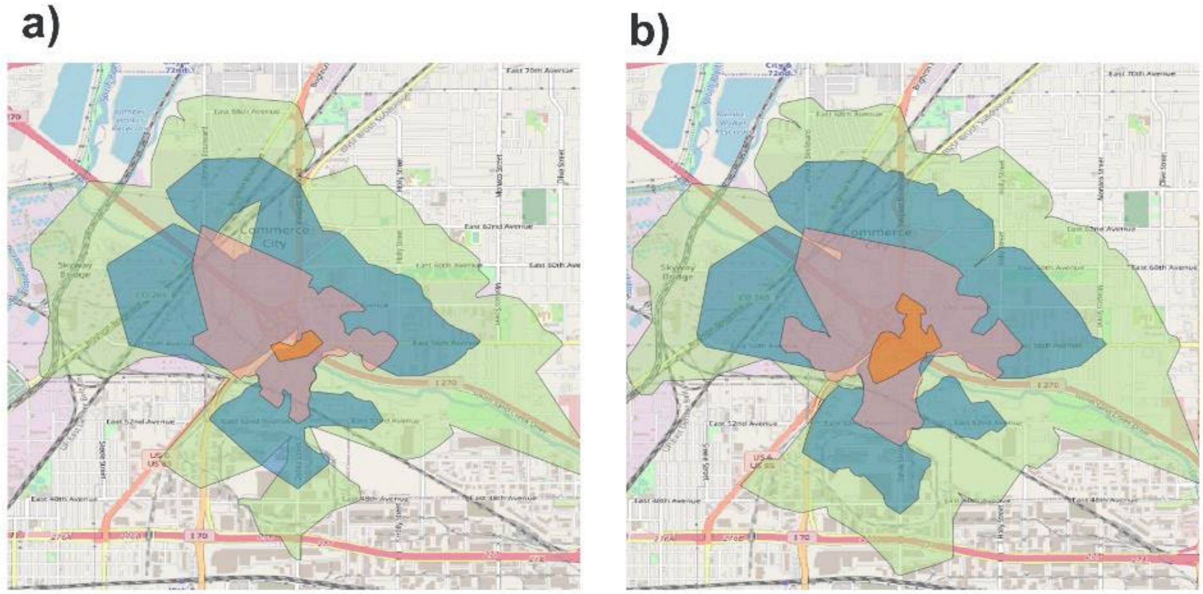

Figure 15. Walk isochrones (a) before and (b) after path additions at a location starting approximately at the Vasquez and I-270 intersection. From smallest to largest by color, the orange, pink, blue, and green isochrones correspond to 10-min, 20-min, 30-min, and 40-min walk isochrones.

3.2 NFRMPO Scenarios

For the NFRMPO study region, no specific project alternatives were considered. Instead, the results show a contrasting location and a differing resolution for MEP to demonstrate the flexibility of scenario formations. Thus, the scenarios calculated and presented focus on the changes from 2015 to 2030 baselines for each mode. For transit, the same statewide alternatives were considered (2030 GHG baseline and 2030 GHG compliance).

Table 6 shows the NFRMPO study regionwide MEP scores weighted by population for the 2015 and 2030 baselines. The magnitude of MEP scores are lower in the NFRMPO study region compared to the I-270 study region due to a two primary factors: (1) the I-270 region is a much smaller study area surrounded by a higher density of jobs and opportunities, while the NFRMPO region is much larger and encapsulates more areas of low-density development (i.e., more exurbs and suburbs); and (2) the I-270 region has a smaller MEP pixel resolution than the NFRMPO region (250 m^2 vs. 1 km^2).

Figure 16 shows the population-weighted drive MEP increased by 0.55% due to development changes (land use, jobs, congestion, and population). The small increase is driven by trade-offs in increased opportunity density and increased congestion, the same as the I-270 baselines. Drive MEP increased from 54.9 in 2015 to 55.2 in 2030. Transit MEP saw modest increases driven by changes to service around Fort Collins in the GHG baseline (Figure 17). Access to jobs also increased and saw jobs MEP increases concentrated on I-25 east of Loveland near the Northern Colorado Regional Airport (Figure 18).

While the NFRMPO drive and transit MEP increased, there were small decreases in the overall population-weighted bike and walk MEP. However, bike and walk MEP increase minimally throughout the region indicating this is due to population growth not aligning with where relative increases in bike and walk MEP occur; this is likely due to more sprawling population and housing growth in locations that do not yet have additional improvements to bike and walk infrastructure. Figure 19 shows the bike MEP increase in raw scores across the region, and Figure 20 shows the proportion of bike MEP change in 2030 (as a whole of the region, not weighted by population) and the proportion of population change in 2030. In Figure 20(a), there is a relative decrease in the proportion of bike MEP around Fort Collins; this does not mean the bike MEP decreased, but instead shows that Fort Collins saw a "slower" increase in bike MEP relative to other areas in the NFRMPO study region. When comparing this to the population proportion change in 2030 in Figure 20(b), there is a concentrated pocket of population growth that outpaces most of the region, in downtown Fort Collins. As a result of these relative differences in bike MEP growth vs. population growth, the population-weighted bike (and walk) MEP decrease slightly from 2015 to 2030. It is important to note that these scenarios do not consider any change to the bike or walking facilities across the NFRMPO region; it would be expected that with increased development and population growth in the region that additional biking and walking facilities would be built, and that these new paths would support the increasing populations to see increased access via biking and walking.

Table 6. NFRMPO study regionwide population-weighted MEP scores by mode in the 2015 and 2030 baselines. The 2030 baselines are "no action" scenarios; for transit this is the GHG baseline (no GHG compliance), and for other modes this means no action taken to change the transportation network.

Scenario	Drive MEP	Bike MEP	Walk MEP	Transit MEP
2015 baseline	54.9	20.7	1.82	1.82
2030 baseline	55.2	19.5	1.57	2.33

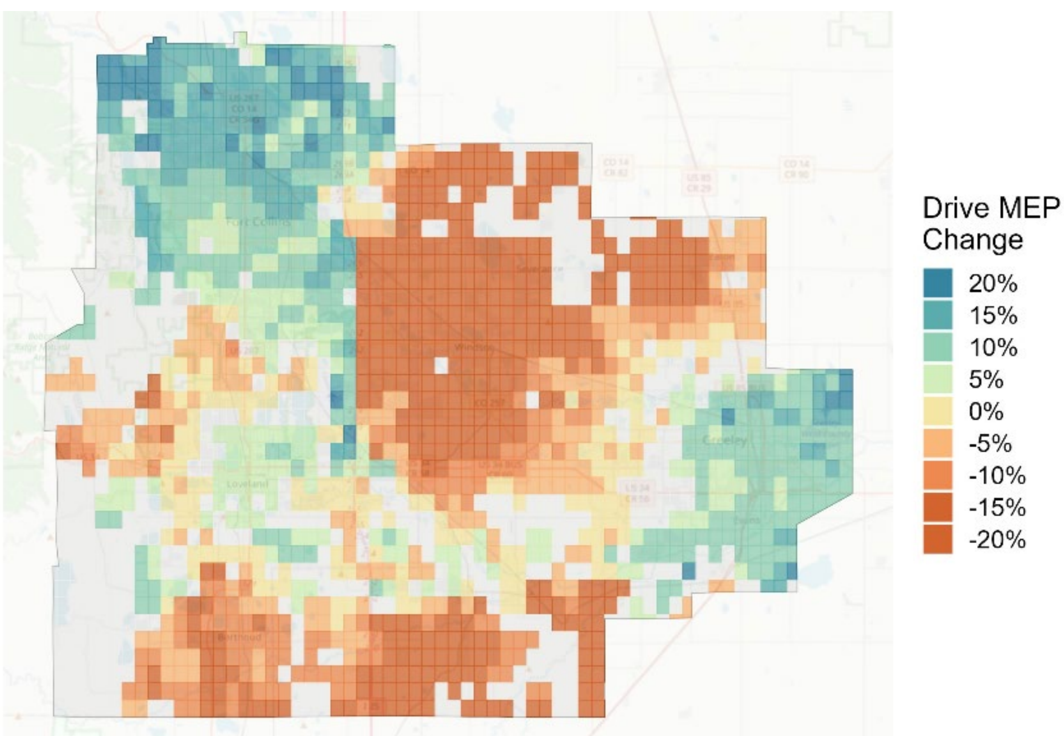

Figure 16. NFRMPO drive MEP change from 2015 to 2030 from land use, jobs, and network

changes.

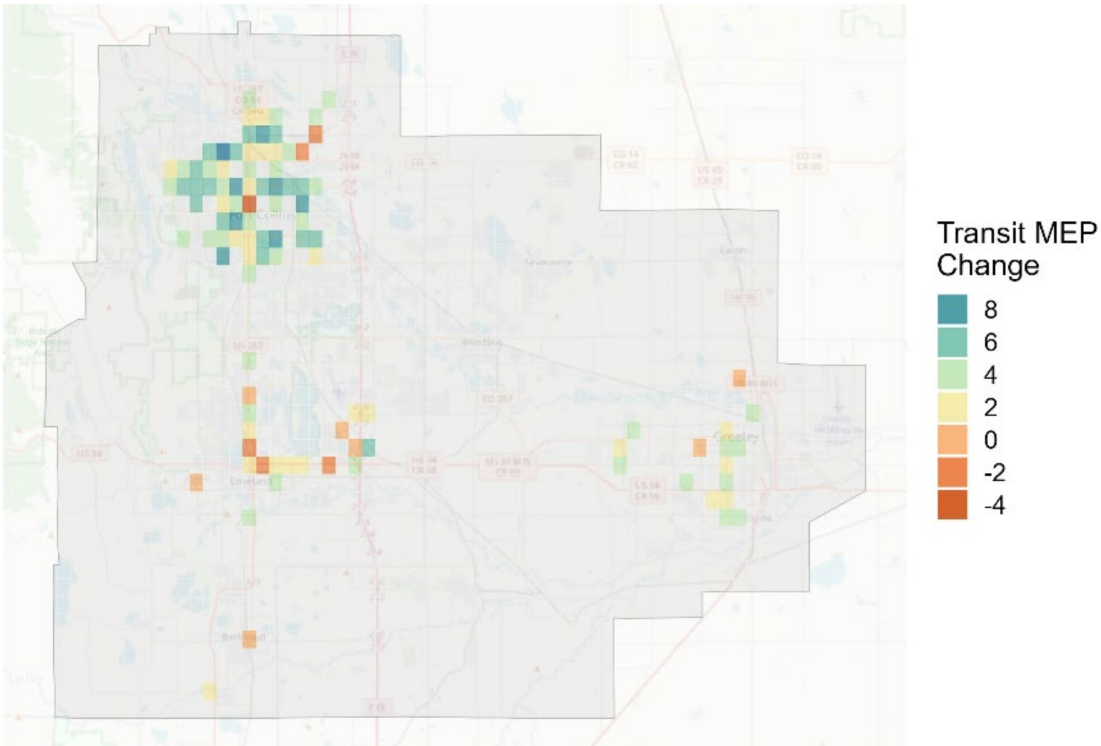

Figure 17. NFRMPO transit MEP change from 2015 to 2030 from land use, jobs, and service changes.

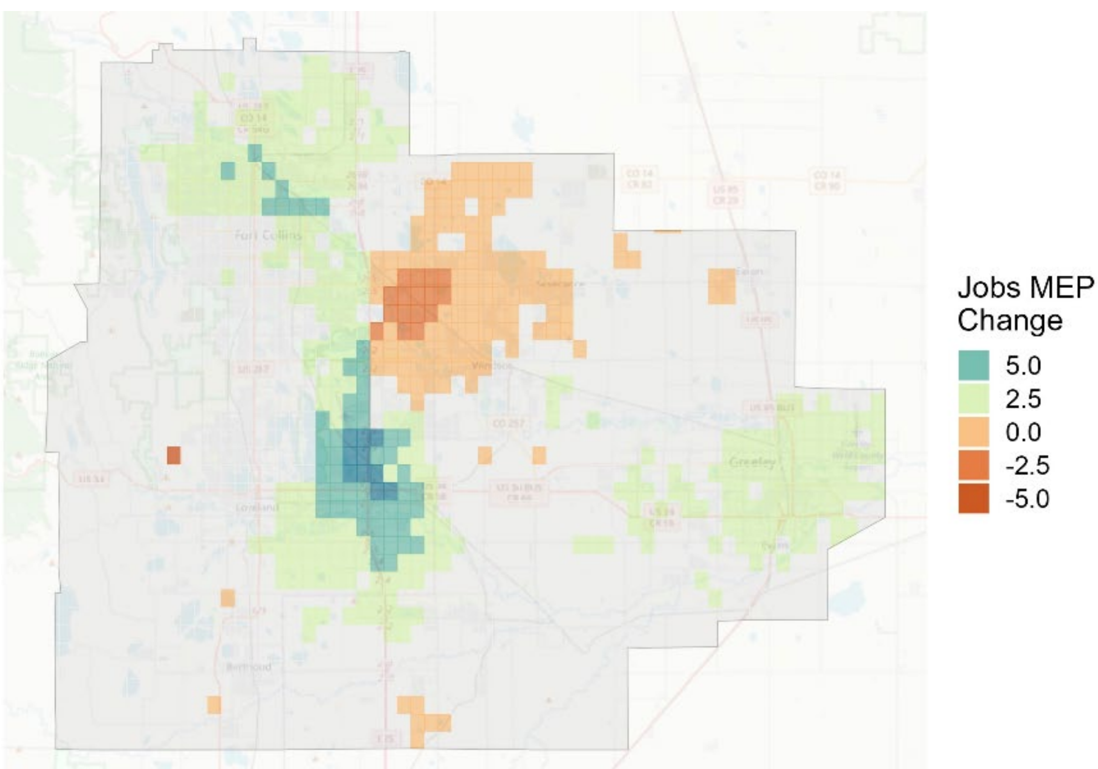

Figure 18. NFRMPO jobs MEP change from 2015 to 2030 (includes network changes).

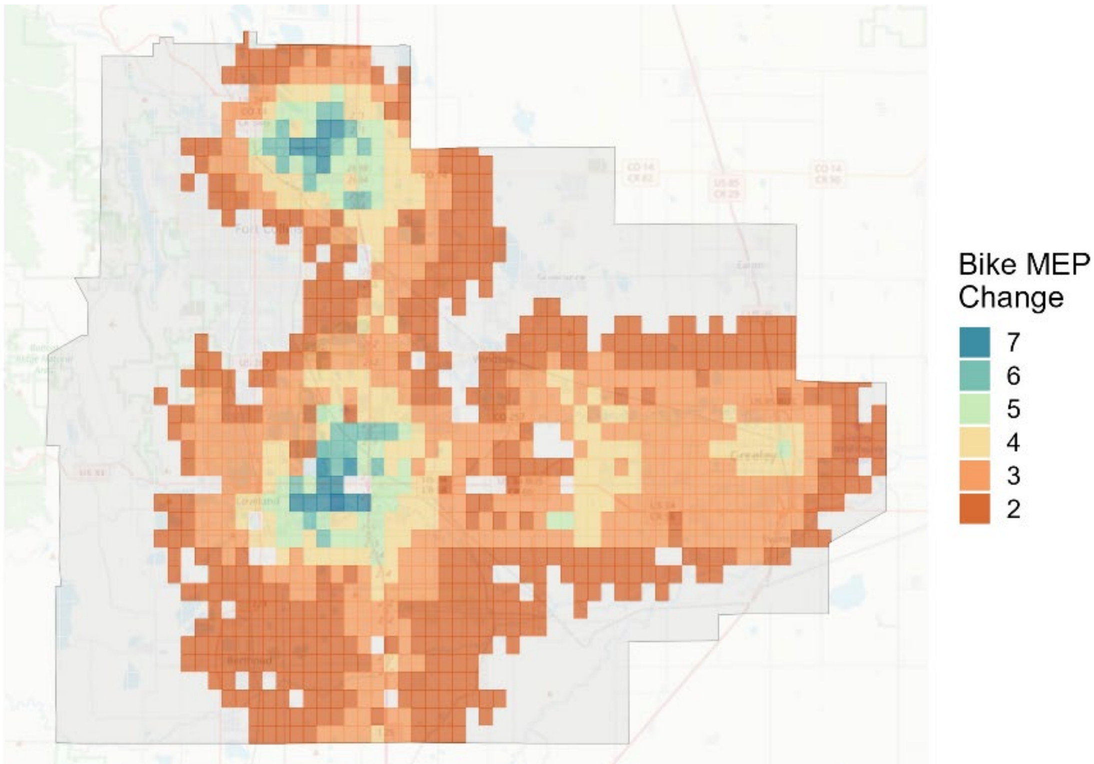

Figure 19. NFRMPO bike MEP change from 2015 to 2030 due to land use, jobs, and network changes.

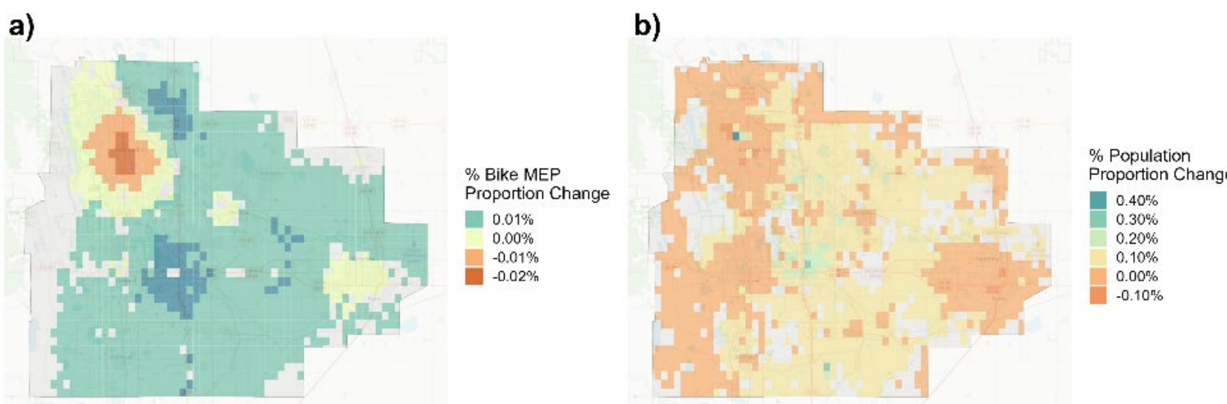

Figure 20. 2030 bike MEP (a) proportion change and (b) population proportion change across the NFRMPO study region.

4. Discussion & Conclusion

The MEP metric can be a valuable tool to measure the quality of mobility across time and space and how energy-efficient access could be impacted by various technological advancements, transport policies, and infrastructure investments. The objective of this study was to demonstrate how the MEP metric could utilize data from CDOT's statewide TDM and demonstrate how MEP can be used as a tool to evaluate the impacts of various transportation projects across the state. While the purpose of this project was not to leverage MEP to make any decisions about current or future projects, this effort and report outline the ways in which MEP could support future project evaluation and decision-making by considering the important dimension of energy-efficient accessibility in transportation project planning.

One of the biggest challenges and lessons learned through this project was figuring out a robust way to consider impacts to biking and walking access in the absence of detailed travel demand modeling of bike and walk modes. To overcome this challenge, OSM network data were utilized with some assumptions on bike and walk travel characteristics to show how the addition of future pedestrian and multimodal paths could impact MEP in specific locations. However, these results don't consider that areas expecting population and housing growth may see additional improvements to bike and walk infrastructure to match increasing development. While the increases to bike and walk MEP in this analysis were small due to small-scale changes considered, it was also shown that there is significant potential for increasing density and development (increasing jobs and opportunity densities) to have strong positive impacts on MEP (especially for public and active transit). Future travel demand modeling and mobility planning should consider more comprehensive and detailed bicycle and pedestrian options, as this could be very valuable to understand holistic potential to improve energy-efficient access now and under different future planning scenarios.

This project focused on demonstrating MEP for a specific project improvement of considering a managed (tolled) lane in Denver vs. general-purpose lane use. Additionally, this project demonstrated the use of MEP to examine energy-efficient accessibility impacts due to increasing development (increasing availability of jobs, denser land use, and population growth). The results show there is additional value in understanding the impact of future development (increasing population, jobs, and opportunities) on MEP, even independent of any specific project; in both the I-270 and NFRMPO study regions, increasing development alone had significant impacts on MEP. As the state of Colorado grows, access to the increasing opportunities and jobs will be an important metric to understand how future transportation planning can prioritize efficient, sustainable, and equitable access.

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