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Climate Change and Urban Transport Sustainability

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Abstract

The 2022 Sea Level Rise Technical Document, published by the US National Oceanic and Atmospheric Administration (NOAA), reports sea level along the US coastline is projected to rise, on average, 10 - 12 inches (0.25 - 0.30 meters) in the next 30 years (2020-2050) (NOAA, 2022). This will create coastal flooding by causing tide and storm surge heights to increase and reach further inland. By 2050, "moderate" (typically damaging) flooding is expected to occur, on average, more than 10 times as often as it does today, and can be intensified by local factors. About 2 feet (0.6 meters) of sea level rise along the US coastline is increasingly likely between 2020 and 2100 because of emissions to date. Failing to curb future emissions could cause an additional 1.5 - 5 feet (0.5 - 1.5 meters) of rise for a total of 3.5 - 7 feet (1.1 - 2.1 meters) by the end of this century. At the same time, cities are experiencing rapid urbanization and population growth with increasing levels of private motorized vehicle ownership and use, a major source of emissions. Non-motorized transport is considered one of the important mitigation strategies to reduce the amount of greenhouse gas emissions and make urbanized communities sustainable. This paper examines the impacts of sea level rise on non-motorized transportation facilities along the coastlines of the State of Delaware using Geographic Information System (GIS) supported by the latest data and models. Results show there is significant damage in the number of facilities if sea level rises between 2 and 6 feet. As sea level rise projection gets higher, the number of facilities with major inundation increases. So the question becomes with trails and bikeways disappearing along the coastlines, is there enough space to bring these sites to the cities that are further inland, noting that vehicle use is at an all-time high, and, there are grass roots movements everywhere asking decision-makers, engineers and planners for more non-motorized transport facilities? This paper also examines the challenging policy, engineering and planning implications of creating non-motorized transport sites and capacities in cities with shrinking available land and space for such facilities.

Keywords

Climate Change, Urban Sustainability, Non-Motorized, Transportation, Sea-Level Rise, Geographic Information System, Complete Streets

1. Introduction

Climate change is described as any significant change in the measures of climate persisting for an extended time span (decades or longer). Many climatic models project that future changes are likely to increase beyond the range of variability experienced in the past. Historical data and trends may no longer be reliable indicators for future climate conditions (US EPA, 2012). Humans are changing the composition of the atmosphere by adding carbon dioxide and visible particulates, called aerosols, mainly by burning fossil fuels. Other activities add methane and nitrous oxide, which along with carbon dioxide form the greenhouse gases. Greenhouse gases are defined as any of various gaseous compounds that absorb infrared radiation, trap heat in the atmosphere, and contribute to the greenhouse gas effect (Knutti, 2010). These include CO_2, methane (CH_4), nitrous oxide (N_2O), and fluorinated gases (F-gases, which include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6)). Greenhouse gases can remain in the atmosphere for varying lengths of time, from a few years to thousands of years. Consequently, the concentration of greenhouse gases increases over time (Division of Energy and Climate, DNREC, 2014). There are several different sources contributing to emission of greenhouse gases. For example, in the United States electricity generation is the largest source of greenhouse gas emissions, followed by transportation. Greenhouse gas emissions caused by human activities increased by 5 percent from 1990 to 2012. In addition to changing the atmospheric concentrations of gases and aerosols, humans are affecting both the energy and water budget of the planet by changing the land surface, including redistributing the balance between latent and sensible heat fluxes. From 1990 to 2013, the total warming effect from greenhouse gases added by humans to the Earth's atmosphere increased by 34 percent. The warming effect associated with carbon dioxide alone increased by 27 percent (United States Environmental Protection Agency, 2014). There are many indicators of climate change. These include physical responses such as changes in the surface temperature, atmospheric water vapor, precipitation, severe events, impacts on glaciers, oceans, land ice, and sea level (Stocker, 2014). In addition, there are several climate stressors caused by climate change such as sea level rise, flooding, increased temperature, etc. Sea level rise and the associated increase in frequency and intensity of storm surges and flooding incidences are among the most worrying consequences of climate change (Koetse & Rietveld, 2009). The 2022 Sea Level Rise Technical Document, published by the US National Oceanic and Atmospheric Administration (NOAA), reports sea level along the US coastline is projected to rise, on

average, 10 - 12 inches (0.25 - 0.30 meters) in the next 30 years (2020-2050). This will create coastal flooding by causing tide and storm surge heights to increase and reach further inland. By 2050, "moderate" (typically damaging) flooding is expected to occur, on average, more than 10 times as often as it does today, and can be intensified by local factors. About 2 feet (0.6 meters) of sea level rise along the US coastline is increasingly likely between 2020 and 2100 because of emissions to date. Failing to curb future emissions could cause an additional 1.5 - 5 feet (0.5 - 1.5 meters) of rise for a total of 3.5 - 7 feet (1.1 - 2.1 meters) by the end of this century

Since transportation facilities and activities have significant effects on climate change and the ecosystem, the concept of clean transportation becomes vital to ensure a safe environment and good quality of life in urban areas and as a result on earth. Non-motorized transport (NMT) is one of the main elements of clean urban transport (Jain, 2022). NMT are travel forms that do not rely on engines. They include walking, cycling, and variations of small-wheeled, human-powered transportation modes. With the exception of walking, these modes utilize non-motorized vehicles such as bicycles, skateboards, push scooters, wheelchairs, and rickshaws. Trips which are shorter in commute are easy to cover by non-motorized modes. These are also the highest trips in the travelling share in cities. But, because of urbanization, private vehicles are growing globally due to their perks of safety, reliability and comfort.

Urbanization refers to the population shift from rural to urban areas, the corresponding decrease in the proportion of people living in rural areas, and the ways in which societies adapt to this change. It is predominantly the process by which towns and cities are formed and become larger as more people begin living and working in central areas. It is predicted that by 2050 about 64% of the developing world and 86% of the developed world will be urbanized. That is equivalent to approximately 3 billion urbanites by 2050, much of which will occur in Africa and Asia. Notably, the United Nations has also recently projected that nearly all global population growth from 2017 to 2030 will be by cities, with about 1.1 billion new urbanites over the next 10 years (Urbanization, Wikipedia, 2022).

With disappearing non-motorized trails, routes and other facilities near the coastal areas, and the increase in urbanization, the question becomes are urban areas and urban planners, engineers and policy makers ready and willing to make up for the lost lands within the urban areas? With increase in auto use, will there be enough land to dedicate to non-motorized facilities? Failure to increase the non-motorized transportation facilities and reduce the volume of fossil fuel vehicles within the urban areas translates into more greenhouse gas effects, a more sustained and severe climate change, and the continuation of the vicious cycle of humans contributing to the harmful impacts on earth.

2. The State of Delaware Study

This research study (conducted by Ziazi, Faghri, & Li, 2018) investigated the ef-

fects of sea level rise on trails and bike routes which were considered as non-motorized transportation facilities in the State of Delaware. The vulnerability of these facilities against rising sea was evaluated based on the distance of inundation, and the maximum depth of water using GIS-based analysis. The results were reported as the level of service (LOS) of facilities under different sea level rise projections. Also, the results of this study showed that there was a significant gap between the number of facilities that will be damaged if sea level rises 6 feet (high projection) rather than 2 feet (low projection). As sea level rise projection got higher, the number of facilities with lower level of service increased.

Geospatial Data: The inventory of existing trails in Delaware were obtained from the Delaware Department of Transportation (DelDOT) and classified by county for further GIS-based analysis. The total mileage of trails in Delaware is 713.5 (mile). Bike routes are defined as roadways that are considered safe for bicyclist. The mileage of existing bike routes in Delaware were calculated as 1715.49 (mile). Based on the application and geographic characteristics, bike routes were clustered into three categories: Statewide, Regional, and Connector.

Topographic Data: A LiDAR-derived digital elevation model (DEM), with a horizontal accuracy of 1 meter, was obtained from the National Oceanic and Atmospheric Administration (NOAA). The DEM was used to estimate the elevation of trails and bike routes centerlines using a mask operation in ArcGIS.

Sea Level Rise Projection: The lowest SLR projection suggests that there will be 2 (ft) rise in the sea level. The highest projection which represents the worst situation estimates 6 (ft) of sea level rise by 2100, and the amount of sea level rise for the medium projection recommended by NOAA is 4 feet (4). These projections are regardless of land subsidence or uplift caused by tectonics plate movements.

Vulnerability Assessment: Assessing the vulnerability of trails and bike routes was done using two measures for each individual facility:

- Mileage of inundation
- Maximum depth of water

The results of the vulnerability assessment were reported as the level of service (LOS) of facilities under each SLR projection by the year 2100.

Results: Four parameters were estimated as result of GIS-based analysis for trails and bike routes:

- The total mileage of affected facilities
- The portion of affected facilities that will remain on land
- The portion of affected facilities that will be inundated
- The total mileage of damaged facilities

Calculating these parameters for each facility was the first step in assessing their vulnerability against sea level rise.

Conclusion of the Study: All the analysis results proved that as sea level rise projection got higher the number of trails or bike routes with lower level of service increased. The number of damaged trails under the medium SLR projection

showed an increase of 56.76% compared to the number of damaged trails under the low SLR projection. This percent increased to 78.9% when the comparison was done between the low and the high SLR projections. To investigate the severity of different SLR projections, comparisons were done based on mileage of facilities. This comparison showed that there will be 60.95% increase in mileage of damaged trails under the medium SLR projection compared to the low projection and this percent will be 90.3% if the comparison was done between the lowest and the highest SLR projections. The results for the bike routes showed that under the low projection bike routes will not vanish. However, the number of damaged bike routes will increase by 50% if sea level rises 6 feet (high projection) rather than 4 feet (medium projection). Also, there will be a 55.48% increase in the mileage of damaged bike routes when the comparison was made between the medium and the high sea level rise projections. In addition, based on the literature review, there are two other climate change stressors that affect transportation especially surface transportation: flooding due to intense precipitation, and increased temperature. The effects of these climatic stressors on non-motorized transportation facilities, and pedestrians and cyclists' travel behavior were not covered in this study.

Table 1 presents the Level of Service (LOS) calculations based on the depth of water and the length of coverage for a low SLR scenario.

Figure 1 and Figure 2 show the distance and percent of affected bike routes.

Figure 3 and Figure 4 show the distance and the percent of affected trails.

Figure 5 and Figure 6 present the different Levels of Service (LOS) for the Sussex and New Castle counties in the State of Delaware.

3. Urbanization

As was previously mentioned in the introduction section of this article, more than half of the world's population now live in urban areas—increasingly in highly-dense cities. However, urban settings are a relatively new phenomenon in human history. This transition has transformed the way we live, work, travel and build networks.

Table 1. Level of service estimation based on depth of water and length of inundation for low SLR scenario.

			Inundation Distance (%)					
			0 - 10	10 - 30	30 - 50	50 - 70	70 - 90	90 - 100
Sea Level Rise Projection	Low (2 ft)	Maximum Depth of Water less than 1 (ft)	LOS A	LOS A	LOS B	LOS D	LOS E	Out of Service
		Maximum Depth of Water More than 1 (ft)	LOS A	LOS B	LOS C	LOS D	LOS F	Out of Service
	Medium (4 ft)	Maximum Depth of Water less than 2 (ft)	LOS A	LOS B	LOS D	LOS E	LOS F	Out of Service
		Maximum Depth of Water More than 2 (ft)	LOS B	LOS C	LOS D	LOS F	LOS F	
	High (6ft)	Maximum Depth of Water less than 3 (ft)	LOS A	LOS C	LOS D	LOS F	LOS F	Out of Service
		Maximum Depth of Water More than 3 (ft)	LOS B	LOS C	LOS E	LOS F	LOS F	Out of Service

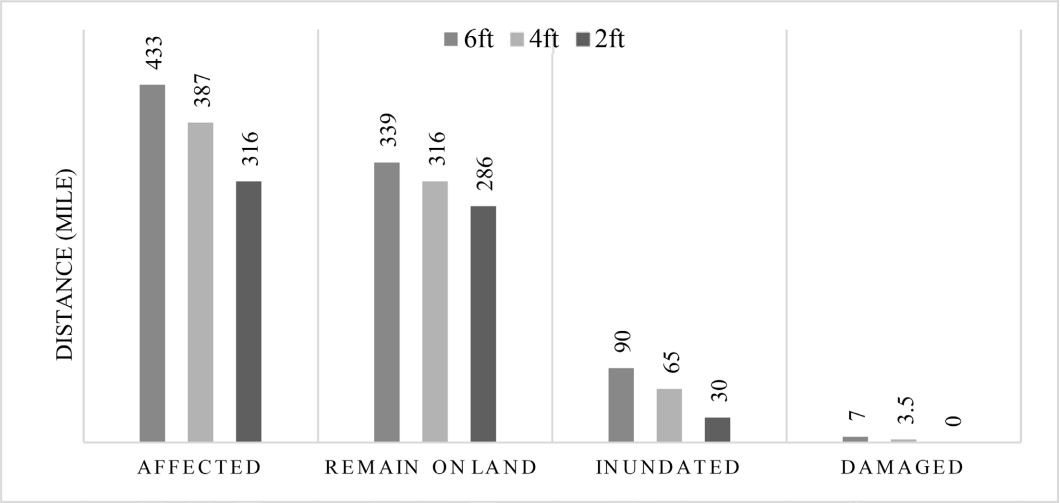

Figure 1. Distance of affected bike routes by sea level rise in Delaware (mile).

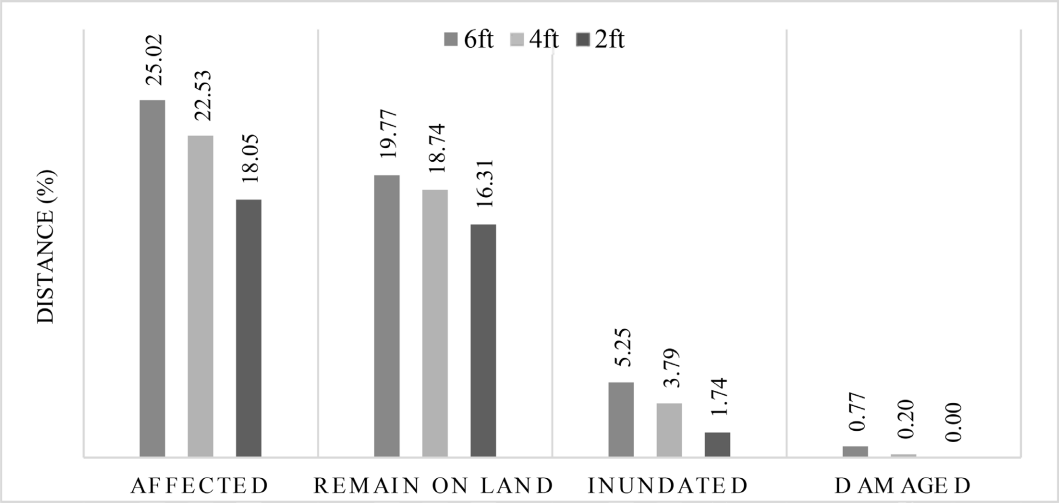

Figure 2. Percent of affected bike routes by sea level rise in Delaware (percent).

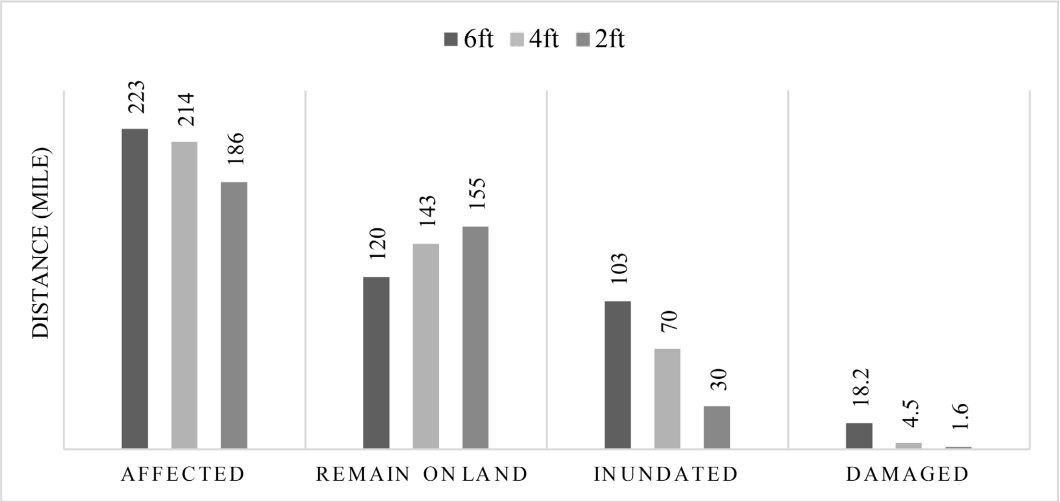

Figure 3. Distance of affected trails by sea level rise in Delaware (mile).

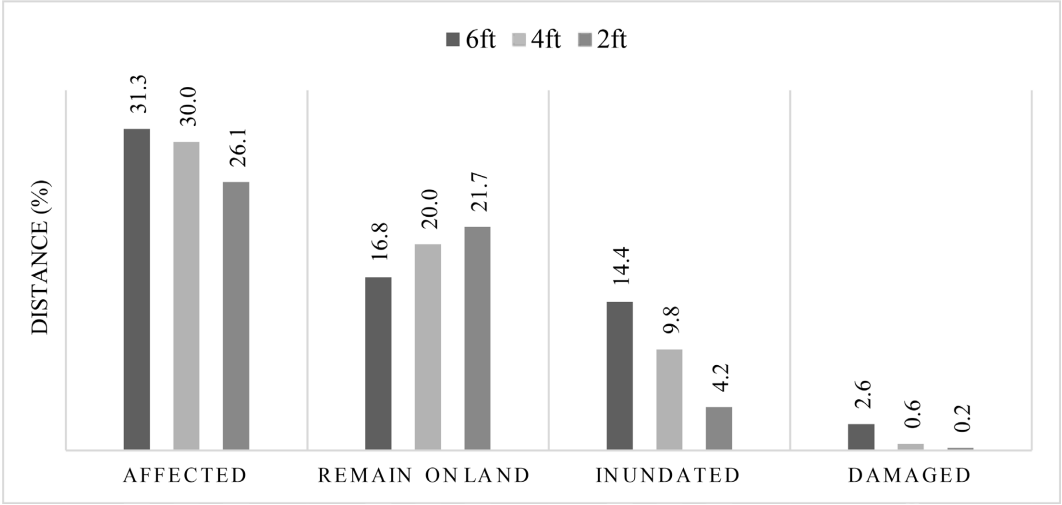

Figure 4. Percent of affected trails by sea level rise in Delaware (percent).

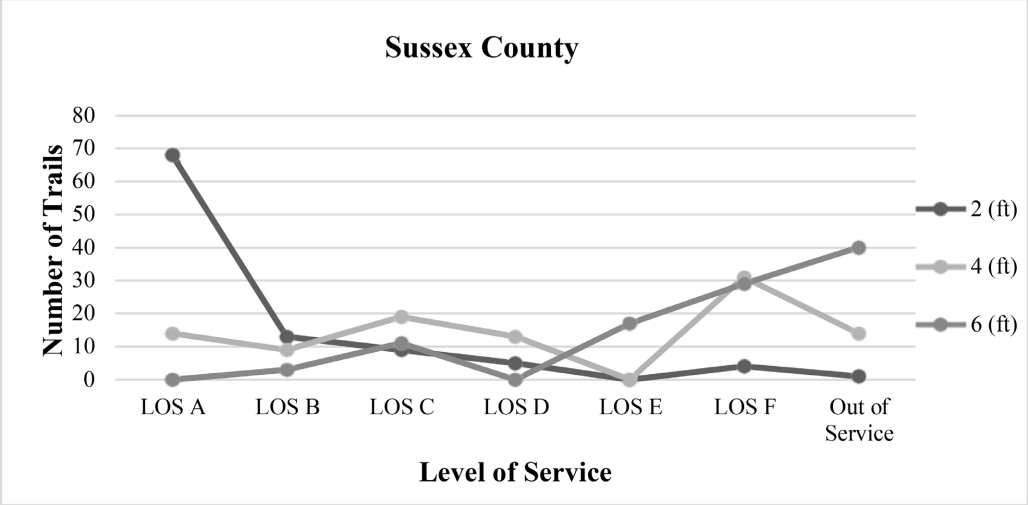

Figure 5. Trail's level of service under three sea level rise scenarios in Sussex County.

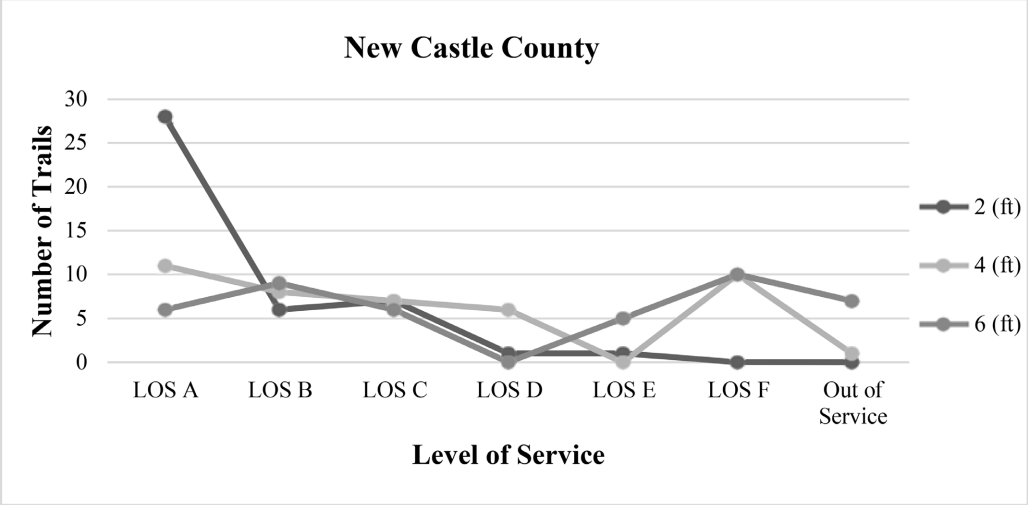

Figure 6. Trail's level of service under three sea level rise scenarios in New Castle.

This following presents an overview of urbanization across the world, extending from the distant past, to present, and projections of future trends (Ritchie & Roser, 2022).

- More than 4 billion people live in urban areas globally.
- The UN estimates 2007 was the year when, for the first time, more people in the world lived in urban than in rural areas.
- Estimates on urban populations vary—mainly as a result of disagreements on the exact definition of an "urban area" and what this includes.
- Just under 1-in-3 people in urban areas globally live in a slum household.
- For most of human history, populations lived in very low-density rural settings. Urbanization is a trend unique to the past few centuries.
- By 2050 it's projected that more than two-thirds of the world population will live in urban areas.
- It's projected that close to 7 billion people will live in urban areas in 2050.
- People tend to migrate from rural to urban areas as they become richer. Living standards tend to be higher in urban areas.

4. The Good News

There is growing momentum across the United Stated and many other countries to implement "complete streets" in every corner of the country. "Complete streets" is a transportation policy and design approach that requires streets to be planned, designed, operated and maintained to enable safe, convenient and comfortable travel and access for users of all ages and abilities regardless of their mode of transportation. Federal agencies have promoted the practice for decades and over the last 15 years, the term *complete streets* has been growing rapidly in popularity (Calloway, 2020). Cities and towns have increasingly been incorporating them into their policies and guidance for new development and redevelopment of existing areas. Examples of successful complete streets can be found around the world and here in the United States. No longer do the nation's youth desire to move outside the city centers like we have over the last 60+ years when we were in search of living the American dream of 2.4 children and a white picket fence. Today's movement of people is heading back into our vibrant and diverse city centers. Real estate and economic trends are showing a reversal of movement back to areas of dense residential and commercial mixed use. Today's generation want to be able to walk or bike from home to work, to shop and back. Many are choosing not to even get a driver's license. They are cognizant of their health and want to live in diverse and thriving downtowns filled with commercial and entertainment destinations.

Around the globe, examples of Complete Streets can be found in all major populated areas. From Europe to Asia to North America, several countries are mastering the method of equal access of transportation to all users. Europe is ahead of the world with their resistance to an automobile centric transportation plan. The cities and towns of Europe (For example Amsterdam, Copenhagen

and London) have existed for centuries and have thrived on being walkable and friendly to all transportation users. When we think of European cities and towns, we picture cobblestone streets, street lighting, shops and boutiques dotting the edges of the rights-of-way. We see little cafés with chairs and tables going to the edge of the elevated space to welcome guests for a drink or a meal. These inviting spaces promote walking and bicycling. The cost of gasoline in Europe also motivates more residents to find ulterior forms of transportation. Asia is known for its public squares and large walkable downtowns. Evolina Ozola summarized it well in her TEDxRiga talk entitled, "Architect's Hands: How Can We Design Better Streets" when she summarized that a complete street is "Where everyone young, healthy, and financially secure as well as those whose income is modest and whose movements are limited can equally take part in mobility and in social life." (TEDxTalks, 2015). Because of centuries of experience, countries all over the world have a good grasp of what works and how their cities and towns can thrive in changing times and provide transportation equity.

5. The Bad News

Owning a car is expensive. Between the price of the vehicle, financing costs, insurance, taxes, and maintenance, owning one—let alone two—cars can drain a family's bank account quickly. According to AAA, for vehicles driven 15,000 miles a year, average car ownership costs were $9561 a year in the US, or $797 a month in 2020. That figure includes depreciation, loan interest, fuel, insurance, maintenance, and fees. Low-income families who cannot afford owning a car rely on non-motorized transportation facilities to walk and/or bike for their transportation needs. The US Census Bureau reports show that low incomes commute by biking and walking far more than affluent Americans.

But, a combination of climate change and Urbanization (the process through which cities grow, and higher and higher percentages of the population come to live in the city) is threatening the integrity of urban infrastructure including non-motorized transportation facilities. The intergovernmental panel for climate change (IPCC) has certified 0.2˚C of increase in mean temperature per decade. Non-motorized transportation is considered as not only one of the major mitigation strategies to reduce the amount of greenhouse gas emissions but also as a solution to bring safety, livelihood, and health back to urbanized communities, especially to those who cannot afford owning a vehicle. Urbanization on the other hand, has reduced the ability of land to absorb rainfall through the introduction of hard, impermeable surfaces. This results in an increase in the volume and rate of surface run-off as less water infiltrates into the ground. Urban pluvial flood risk is expected to increase significantly in the future as a result of climate changes and demographic shifts: the former is likely to increase the magnitude and frequency of extreme storm events, the driving force of pluvial flooding, while the latter will increase exposure and hence, risk.

This proves the importance of identifying facilities that are vulnerable to the

effects of climate change and urbanization, in order to start adaptations as early as possible. Walking, trails, and bike routes are the non-motorized transportation facilities that need to be studied in urban areas. The distance of inundation (distance of trails and bike routes that will be under water), and the maximum depth of water on affected facilities are estimated using the latest climatological and urban hydrological models. The negative consequences of non-motorized transportation facilities inundation on families who rely on such facilities for their transport needs will be studied.

6. Best Practices and Policy Implications

The National Complete Streets Coalition (NCSC) identifies the elements of a comprehensive Complete Streets policy to help communities develop and implement policies and practices that ensure streets are safe for people of all ages and abilities, balance the needs of different modes, and support local land uses, economies, cultures, and natural environments (Smart Growth America, 2018).

Since its creation in the 2000s, the Complete Streets movement has evolved to focus far more on implementation and equity. In response to these changes, the Coalition updated and revised the original 2000s-era Complete Streets policy framework to require more accountability from jurisdictions and provisions that account for the needs of the most vulnerable users. These 10 policy elements, revised in 2018, are based on decades of collective expertise in transportation planning and design, created in consultation with NCSC's steering committee members and a group of national stakeholders consisting of engineers, planners, researchers, and advocates.

The elements serve as a national model of best practices that can be implemented in nearly all types of Complete Streets policies at all levels of governance. For communities considering a Complete Streets policy, this resource serves as a model; for communities with an existing Complete Streets policy, this resource provides guidance on areas for improvements.

An ideal Complete Streets policy includes the following:

Vision and intent: Includes an equitable vision for how and why the community wants to complete its streets. Specifies need to create complete, connected, network and specifies at least four modes, two of which must be biking or walking.

Diverse users: Benefits all users equitably, particularly vulnerable users and the most underinvested and underserved communities.

Commitment in all projects and phases: Applies to new, retrofit/reconstruction, maintenance, and ongoing projects.

Clear, accountable exceptions: Makes any exceptions specific and sets a clear procedure that requires high-level approval and public notice prior to exceptions being granted.

Jurisdiction: Requires interagency coordination between government departments and partner agencies on Complete Streets.

Design: Directs the use of the latest and best design criteria and guidelines and

sets a time frame for their implementation.

Land use and context sensitivity: Considers the surrounding community's current and expected land use and transportation needs.

Performance measures: Establishes performance standards that are specific, equitable, and available to the public.

Project selection criteria: Provides specific criteria to encourage funding prioritization for Complete Streets implementation.

Implementation steps: Includes specific next steps for implementation of the policy.

The complete implementation of the guidelines shown above can be found in the references at the end of this article.

7. Conclusion

More and more people are leaving rural areas and moving into urban metropolis. At the same time, the impacts of climate change are making life within urban areas more challenging. Fossil-based fuel vehicles are one of the primary sources of the greenhouse gas effects that are directly contributing to climate change. The increase in the utilization of the different modes of public transportation, increasing the non-fossil-fuel-based vehicles such as electric vehicles, and expanding the Complete Streets concept within urban areas will have a curtailing impact on climate change. This article specifically focused on the impact of seal level rise on non-motorized transportation facilities and how planners, engineers and policy makers can prepare themselves for the near and distant future. If appropriate actions are not taken now, the vicious cycle of human appetite for non-sustainable transportation systems and contribution to the climate change will continue, making earth unlivable for future generations.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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