ASSESSING THE TRANSPORTATION ADAPTATION OPTIONS TO SEA LEVEL RISE

for Safety Enhancement in RITI Communities through a Structured Decision-Making Framework

FINAL PROJECT REPORT

by

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16. Abstract

Through a structured decision-making framework, this study aims to better understand the key factors influencing transportation adaptation planning in practice. Qualitative, semi-structured, in-depth interviews with various stakeholders were conducted to identify the main concerns, challenges, objectives, tradeoffs, and evaluation variables in transportation adaptation planning. Stakeholders were identified through preliminary interviews with transportation planning experts from the metropolitan planning organization using typical case and snowball sampling methods. Key aspects related to the major concerns, objectives, priorities, adaptation plan evaluations, implementation challenges, and potential conflicts and tradeoffs are identified. Major barriers to adaptation plan development and implementation include lack of resources, competing with more urgent needs, conflicts with other planning objectives, lack of holistic view, working in silos, mismatched and outdated information, uncertainty in future scenarios, and action inertia. To overcome these challenges, we propose 1) more efforts to understand community values, develop strategic goals, and identify their priorities in order to balance the tradeoffs 2) collaboration with other sectors to develop a holistic view of resilience and strategic plans that achieve multiple planning goals 3) collaborate with diverse stakeholders to reduce spatial and temporal information mismatches and to create adaptive plans that can accommodate multiple scenarios with uncertainty 4) conduct community outreach and stakeholder engagement from the beginning to build support, consolidate resources, and eliminate social inertia for plan implementation.

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APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$candela/m^2$	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	$candela/m^2$	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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EXECUTIVE SUMMARY

As one of the most widespread and major climate change results, sea level rise (SLR) has become a pressing concern to coastal communities and has greatly impacted the efficiency of coastal transportation systems. Because of heavy dependence on natural resources, settlements in relatively isolated fringe land, limited accessibility to services and alternative economic activities, and a lack of resources and tools for adaptation, vulnerable communities' livelihoods and transportation safety are particularly at risk to SLR and exacerbated coastal flooding. However, despite numerous studies on the vulnerability of transportation systems to sea level rise, there is a lack of understanding of the key factors influencing transportation adaptation planning in practice.

To better understand the key factors influencing the transportation adaptation planning process in practice, this project proposed to explore the concerns, objectives, plan development process, and evaluation criteria in a structured decision-making framework by achieving the following objectives:

- Understand stakeholders' perceived challenges and objectives with the projected SLR.
- Understand stakeholders' value preferences and priorities in adapting to SLR.
- Identify the key factors to evaluate adaptation options in the adaptation planning process.
- Identify potential conflicts and tradeoffs in the transportation adaptation decision-making process.

Through qualitative, semi-structured, in-depth interviews with relevant stakeholders, this project collected firsthand data to understand the key concerns, challenges, objectives, tradeoffs, and evaluation factors in transportation adaptation planning. Stakeholders were identified through preliminary interviews with transportation planning experts from the metropolitan planning organization using typical case and snowball sampling methods. A total of 29 Stakeholders with various backgrounds were identified, such as State, City and County transportation and operation agencies; facility management, transit agencies, climate scientists, environmental agencies, non-profit organizations, community groups, and private sectors. The diverse backgrounds of interviewees ensured the researchers heard perspectives from various channels, which increases the credibility of this qualitative research.

Key aspects related to the major concerns, objectives, priorities, adaptation plan evaluations, implementation challenges, and potential conflicts and tradeoffs are identified. The following major barriers to adaptation plan development and implementation have been identified: lack of resources, competing with more urgent needs, conflicts with other planning objectives, lack of holistic view, working in silos, mismatched and outdated information, and uncertainty in future scenarios, as well as associated action inertia. To overcome these challenges, we propose 1) More efforts and research should be devoted to understanding community values, developing strategic goals, and identifying their priorities in order to balance the tradeoffs. 2) Collaboration with other relevant sectors to develop a holistic view of resilience and strategic plans that reduce future risks while remaining compatible with other planning goals. 3) Collaborate with diverse stakeholders to improve the coordination of spatial and temporal information mismatches in decision-making and to create adaptive plans that can be easily altered to accommodate multiple scenarios with uncertainty. 4) Conduct community outreach and stakeholder engagement from the beginning to build support, consolidate resources, and eliminate social inertia for plan implementation.

The identified objectives, vulnerability, decision-making factors, plan evaluation criteria, and implementation challenges provide a better understanding of the key factors influencing transportation adaptation planning in practice. The findings are not only important for the state of Hawaii, but they also have the potential to be generalized to RITI communities in other coastal regions. Communities in a comparable context could apply the lessons learned to develop their adaptation plans, improve the adaptation planning process, evaluate adaptation options, and build community-agency partnerships. The findings could also be used to guide further data collection to develop more comprehensive modeling and evaluation of adaptation options. Additionally, the proposed recommendations could also be used by other infrastructure sectors in enhancing their adaptation planning processes.

CHAPTER 1. INTRODUCTION

Sea level rise (SLR), as one of the most wide-spread and important climate change impacts, has become a pressing threat to communities in coastal regions (National Research Council, 2008). Due to the Greenhouse Gases already emitted, climate change is on track to raise sea level by one to three feet by the end of the century (2100), even with the most aggressive emission cures (Nicholls and Cazenave, 2010; Pachauri et al., 2014). The conservative IPCC Fifth Assessment Report projects that the earth is expected to experience an additional SLR of 0.26 to 0.82 meters by the end of this century (Pachauri et al., 2014). Semi-empirical models show that higher rate of SLR (i.e. 1 to 1.5 meters) is more likely to be reached by 2100 (Grinsted, Moore et al., 2010, Parris, Bromirski et al., 2012, Rahmstorf, 2007). In the near term, the rising sea level plays a role in increasing the frequency and magnitude of tidal flooding, shoreline erosion, and hazards from storms (NOAA, 2018, NOAA, n.d.).

Hawai‘i is especially vulnerable to SLR given the geographic and topographic situation of the islands (Keener, 2013). In Hawai‘i, sea level has risen at approximately 1.5 mm/yr (0.6 in/decade) over the past century (NOAA, n.d.). With this trend, king tides have been found to be higher than average in recent years. Seasonal flooding, coastal erosion, inundation, and interaction with the groundwater table are also apparent threats in Hawai‘i. Flooding driven by these factors has become more tangible in the past several years (Habel et al., 2017). Pope (2017) listed evidence of the detrimental effect of the king tides on development near Hawai‘i's shoreline. With high tides and heavy rains, the roads in the Māpunapuna industrial district of Honolulu have been submerged waist-deep because storm drains were backed up with high ocean water (SOEST, n.d.).

In particular, the livelihoods and transportation safety of vulnerable communities are at more risk to SLR and exacerbated coastal flooding due to their heavy dependence on natural resources, settlements in relatively isolated fringe land, limited accessibility to services and alternative economic activities, and lack of resources and tools for adaptation (Green et al., 2009). SLR could cause the loss of rural, isolated, vulnerable communities’ safe access to community resources and services (Bronen, 2010). The preliminary analysis from the CSET Year 2 project “Assessing the Vulnerability of Transportation Infrastructure to Sea Level Rise for Safety Enhancement in RITI Communities” shows over 30 miles of coastal roads on the island of O‘ahu are at risk during a current annual tidal flooding event. The number would increase with further SLR. Community engagement in the Year 2 project confirms that travel delays, trip cancellations, and route detours have been experienced by residents across the island. Work-related trips, grocery trips, and recreational trips have been greatly affected. Analyses show the accessibility reduction due to flooding is unevenly distributed across the island. Residents in the north part of the island near Kahuku, the east part such as Hawai‘i Kai, and the central part near Honolulu Harbor would experience more impacts from tidal flooding than others. These communities also have a low level of transportation accessibility to employment, school, grocery, and recreational opportunities, even without coastal flooding. With sea level rise, rural and relatively isolated communities, where a high percentage of Native Hawaiians happen to live, such as the North Shore, Kahalu‘u, and Waimānalo, are concerned about being cut off from emergency access during extreme events.

However, despite the findings regarding the impacts of SLR on transportation infrastructure from previous studies and the Year 2 CSET project, there is a lack of understanding of how the different stakeholders perceive such risks and how they plan to adapt to these risks in the future. It is unclear what values different stakeholders’ would prioritize in adaptation. It also remains a question of whether

these values and priorities are consistent with the estimated impacts and vulnerabilities. For example, the network analysis in the Year 2 project reveals that recreational accessibility would not be affected much compared with other opportunities. However, communities identified recreational trips as being heavily affected. Whether the differences in findings are caused by the community's value preference should be further explored for adaptation.

The impacts of sea level rise on the transportation system would also depend on proactive adaptation actions, including hard structure protection for critical transportation infrastructure, community actions, and contextual changes. Parry et al. (2007) summarized three types of adaptation, namely protection, accommodation, and planned retreat adaptation options. Protection involves the hardening of a system in its location to withstand the impacts of changing conditions, such as the use of seawalls, shoreline hardening, or elevated highways. Accommodation refers to adjustments made to the current system to changing natural conditions, including strengthening flood-proofing regulations, sand-dune replenishment, low-impact development, or green infrastructures that help to mitigate flooding at the community level. The planned retreat involves relocation of structures to avoid impacts, such as providing tax incentives for relocation or implementing shoreline construction setbacks. More research is needed to understand people's attitudes toward these adaptation strategies.

To addresss the sea level risks that would affect the transportation access, especially in RITI communities, this project proposed to explore the key factors influencing transportation adaptation planning to SLR and coastal flooding in a structured decision-making framework by achieving the following objectives:

- Understand stakeholders' perceived challenges and objectives with the projected SLR.
- Understand stakeholders' value preferences and priorities in adapting to SLR.
- Identify the key factors to evaluate adaptation options in the adaptation planning process.
- Identify potential conflicts and tradeoffs in the transportation adaptation decision-making process to facilitate community-agency partnerships.

The findings not only have practical significance to the state of Hawai'i but also have the potential to be generalized to RITI communities in similar coastal regions. The lessons learned in the decision-making process could be applied by communities in a similar environment. The approach and planning framework could be used to develop transportation adaptation plans, evaluate adaptation options, and build community-agency partnerships in other places.

To achieve the above objectives, the report is organized into the chapter listed below.

Chapter 1 presents the introduction and objectives of the study.

Chapter 2 provides a review of related concepts and knowledge from the literature.

Chapter 3 describes the data and methodology of the study.

Chapter 4 identifies the findings related to the decision-making process, including problem identification, planning objectives, system vulnerability, adaptation options, and evaluation factors.

Chapter 5 summarizes the findings, identifies the barriers in the adaptation planning process, and proposes recommendations.

CHAPTER 2. LITERATURE REVIEW

Many researchers and scientists believe that the impacts of climate change and sea level rise (SLR) are inevitable. Global mean sea level has been rising for over a century, and the rate of SLR is accelerating (Nerem et al., 2018). NOAA predicts that global mean sea level will rise at least 8 inches by 2100 (Paris, 2012). The transportation community faces significant challenges as a result of climate change (Filosa and Oster, 2015). Climate change impacts such as changes in long term average temperatures, precipitation patterns, increased storm events and increasing sea levels all have direct implications for transportation system planning, design, construction, operation, and maintenance (Filosa and Oster, 2015). Many studies have been conducted to assess the vulnerability of transportation systems to the projected risks (Lu and Peng, 2011, Titus, 2002) and evaluate the effectiveness of adaptation options. Koetse and Rietveld (2009) compiled the first systematic inventory of the state of knowledge on the consequences of climate change on transport systems. Many transportation agencies in the United States have also started to assess the risks their transportation systems and operations face because of climate change (Filosa and Oster, 2015). However, despite these efforts, the current research on climate risks, adaptation, and planning in transportation sector is still in its infancy (Wang, Qu et al., 2020).

While the urgency to adapt to sea level rise and climate change is undoubted, there are also many barriers to selecting and implementing transportation adaptation measures, especially at the local level (Aultman-Hall and Dowds, 2016, Dowds and Aultman-Hall, 2015a, Dowds and Aultman-Hall, 2015b). Based on interviews with practitioners in state departments of transportation in the United States and a review of Federal Highway Administration (FHWA) pilot projects, Dowds and Aultman-Hall (2015a) identified uncertainty about future climatic conditions, the need for additional vulnerability-modeling tools, conceptual uncertainty about assessing asset criticality, and lack of funding all impeding adaptation at the state and local level. Aultman-Hall and Dowds (2016) discovered similar findings that variability and uncertainty about climate threats, lack of tools, limited human and financial resources all make it difficult for transportation agencies to adapt to climate change. In addition, Aultman-Hall and Dowds (2016) noted that the transportation system's interdependence and a large number of stakeholders and organizations engaged exacerbate the difficulties to adapt. They highlight the need for collaboration with clearly defined roles between state and local agencies in order to maximize the process's efficacy and efficiency (Aultman-Hall and Dowds, 2016).

2.1. Participatory Adaptation Planning

The need to include a diverse variety of stakeholders in addressing climate change has been recognized in numerous studies. According to Sheppard, Shaw et al. (2011), effective sea level rise adaptation strategies will require the combined efforts of all levels of government, private sectors, and community members acting together. Active participation is necessary to ensure that climate change adaptation plans match local needs and resources (McCarthy et al., 2001). The planning process should include vulnerability and risk assessment, as well as community-level assessments (Archer et al., 2014). In this process, Mastrandrea et al. (2010) highlight the need for sector-specific information, institutional flexibility, and sharing knowledge and technology with a range of stakeholders. These stakeholders include urban planners considering setbacks and capital improvement plans, engineers designing storm water and wastewater management systems, shoreline erosion protection, and flood risk-reduction measures. Experts such as scientists and researchers providing the latest scientific information on global and local CO2 emission and the future SLR projection, the private sectors managing near, midterm, and

future capital investment plans, council members making policies about climate adaptation and mitigation, and the general public and their specific needs(Stammer, Van de Wal et al., 2019) are also included. National Academies of Sciences and Medicine (2016) mentioned that collaboration with multi-stakeholders to share experiences, and knowledge could foster more commitment and generate more viable instruments toward a more resilient society.

The United Nations Development Program released "Adaptation Policy Frameworks" for developing climate change adaptation strategies, with an emphasis on "grassroots stakeholder participation" (Few et al., 2007). A community adaptation plan is a community-based and-led process based on local needs, knowledge, and capacity (McNamara and Buggy, 2017). Because each region has unique identities, problems, and needs that need to be addressed in SLR adaptation planning process (Carpenter, 2018), it is important to build the capacities of local communities to prepare, manage and adapt to rising sea levels. By recognizing the unique characteristics of the community, climate adaptation plan can stimulate awareness regarding future risks, exposure, and vulnerability within the community (Dodman and Mitlin, 2013). As a result, communities should be able to construct sea level rise adaptation plans by establishing goals and priorities, evaluating funding possibilities, and proposing context-sensitive approaches (Carpenter, 2018). Community-Based Adaptation (CBA) can address the social, economic, and political drivers of vulnerability as it usually engages more diverse and vulnerable populations (Forsyth, 2013).

Because climate change is inherently uncertain and the benefits of adaptation are difficult to quantify in the short term (Kim and Kang, 2018), there are concerns about community-based data collection and the utilization of such information for decision-making. The participatory processes should try to avoid the overwhelming scale of the problem, massive uncertainty, and scientific abstraction (Sheppard, Shaw et al., 2011). In particular, three examples from Korea, Nepal, and United States show how public participation helps to transfer scientific knowledge and engage the community in climate adaptation.

The first example is the community participatory planning in Saebat Maeul, Korea. The planning process started with a review of the impact of climate change in the area to establish a community plan that integrates climate change adaptation (Kim and Kang, 2018). In the process, they tried to use an effective communication method since the concept ‘climate change adaptation’ was still unfamiliar to a majority of residents in Korea. The author shifted scientific knowledge to local knowledge by softening the term “climate change” to “more hot weather” or “more rain”. More community residents and stakeholders began to draw attention to the study since they could easily understand the terms. In order to enhance communication between community members and planners, they asked for help from community coordinators who were designated to ensure smooth implementation of community revitalization projects. After gathering the ideas and thoughts from community, a community’s specific needs were identified using text mining methods such as keyword analysis and word clustering, frequency analysis, and association rule analysis (Kim and Kang, 2018).

The second example is a study conducted by (Regmi et al., 2016) in Nepal from 2009 to 2011 with mixed methods of data collection, including focus group discussions, district-level workshops with multiple stakeholders, and semi-structured interviews. Semi-structured interviews were conducted from selected households, practitioners, key informants, and policy makers, in order to measure the perception of the benefits of climate change adaptation planning and interventions. The focus group discussions had 12 community-level discussions to complement the household survey data analysis. The climate change

adaptation interventions focus on reducing vulnerability and increasing the adaptive capacity of vulnerable households and communities. It provides the opportunity to gather different perspectives from different groups of stakeholders.

The last example comes from the city of Davis, California, which explores how community participation affects the climate protection planning process (Wang, 2009). The city formed the Climate Action Team (CAT) to develop a deeper understanding of issues associated with climate change. In order to develop a more inclusive and effective action plan, the city incorporated opinions and knowledge from local residents, local community leaders, professionals, business groups, environmental non-governmental organizations, and administrative representatives, as well as knowledge from the CAT, into the action plan. The planning process seeks to ensure that all participants have an equal opportunity to participate, that plain language is used rather than jargon, that the process is transparent, legitimate, and trust-building and that power distortions are minimized through careful listening, interpretation, and facilitation in subgroup activities at the community workshops. These processes increased public awareness of climate action issues and provided the connection to build consensus on future climate issues.

In summary, with limited time and resources, it is critical to assess how SLR adaptation planning is prioritized and whether this prioritization is equitable and justifiable for all individuals or groups. Improved communication between resilient communities and their representatives empowers resilient communities to advance critical agendas, organize around a common hazard, or receive support from non-governmental organizations or researchers who can bring new adaptation methods to improve the city- and national-level policies. (Archer, Almansi et al., 2014). Few et al. (2005) described that working with small groups and using a range of participatory tools is the best way to support active participation. For example, facilitated discussions, small group discussions, ranking exercises, and group policy mapping tools in the community workshops bring forth a better quality of community-based information. Community-based adaptation can be utilized as a governance instrument for risk management related to climate change, as this strategy has synergies with broader sustainable development objectives. (Heltberg, Siegel et al., 2009). Community-based adaptation can also address the vulnerability issues based on local perceptions and risks.

Finally, Regmi et al. (2016) discussed concerns about favoritism and the frequently asked the question "who is involved," and noted that CBA strategies may benefit primarily the "less susceptible" members of the community due to their level of resource accessibility, and that greater attention should be paid to vulnerable groups during the process. Tavasszy emphasized the importance of integrating research, addressing specific substantive gaps, and performing methodological work at the global and regional levels in representing the needs of vulnerable populations to SLR (National Academies of Sciences and Medicine, 2016). To reduce vulnerability among these specific social groups, it is necessary to assess the broader socioeconomic impacts of climate adaptation, including environmental justice and equity concerns, to examine the needs of vulnerable population groups, and to identify strategies to address their transportation, mobility, and other needs (National Academies of Sciences and Medicine, 2016).

2.2 Structured Decision-Making Framework

Based on decision theory and risk analysis, structured decision-making (SDM) provides an organized and transparent framework to solve complex decision problems. As a collaborative and facilitated

application of multiple objective decision-making and deliberation methods, SDM combines analytical methods from decision analysis and insights into human judgment and behavior (Gregory et al., 2012). By analyzing management objectives, potential alternatives, and decision consequences as separate components in a comprehensive decision framework, SDM clarifies objectives, facilitates multi-disciplinary stakeholder involvement, and elucidates priorities, preferences, tradeoffs, uncertainty, and risk tolerances, thus bringing transparency to the decision process (Martin et al., 2009). Rather than prescribing a preferred solution, SDM tries to aid and inform decision makers (Gregory et al., 2012). It helps to integrate scientific knowledge, technical analysis with value-based deliberations and policy-making (Martin et al., 2011). Originally used in natural resource management, environmental management, and conservation (Gregory et al., 2012, Martin et al., 2009, Peterman and Anderson, 1999), SDM has been gaining popularity in climate change and SLR adaptation in recent years (Martin et al., 2011, Nichols et al., 2011, Ogden and Innes, 2009, Ohlson et al., 2005). While an SDM method cannot guarantee successful outcomes, it provides a sensible decision-making process for multi-dimensional decisions defined by uncertainty, diverse stakeholders, and challenging trade-offs (Gregory et al., 2012).

There are generally six steps in SMD, especially for climate change adaptation (Gregory et al., 2012, Ogden and Innes, 2009, Ohlson et al., 2005), as shown in Figure 2-1. It presents a simple, straightforward, flexible planning framework based on an adaptive management cycle. Adaptive management is the process of adjusting decisions based on the latest scientific evidence and evolving future SLR projections iteratively. An ideal adaptive management often includes the clearly defined problem, established decision criteria, identification of relevant information, option evaluation, and effective monitoring and review (Gregory et al., 2012).

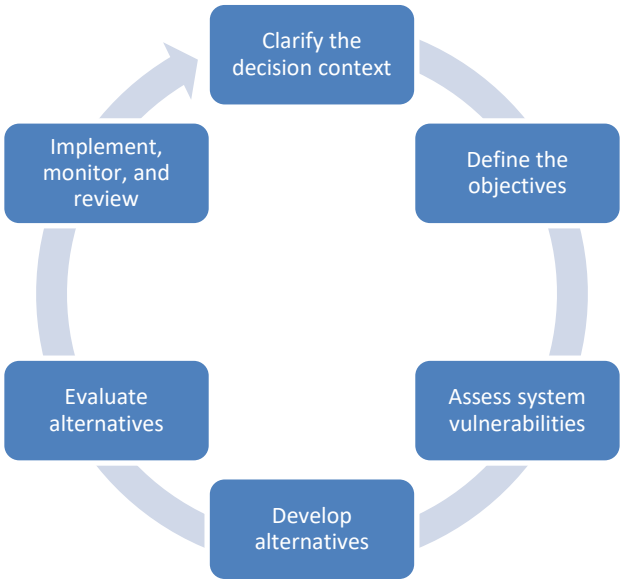

Figure 2. 1. Structured Decision Making Framework

2.2.1. Clarify the decision context

The first step entails identifying the problem and outlining the scope and constraints of the problem. It usually begins by stating the challenge and the required decision or evaluation context. What is the main driver of the problem? Who are the decision-makers? The problem statement should clearly identify the scope and scale of the issues being addressed both in terms of space and time. This should include, where appropriate, a brief review of all key biophysical, socioeconomic, policy, and institutional concerns. This initial step of SDM will establish a road map for the decision-making process.

2.2.2. Define the objectives

After defining the problem and decision-making context, objectives should be clearly stated. Objectives define things that matter, such as resources or outcomes that stakeholders care about and things that may be vulnerable to climate change. In order to avoid overcomplicating the process, management objectives should be comprehensive, concise, measurable, and controllable (Ohlson et al., 2005). Performance measures are specific metrics that help to analyze and assess the objectives. Objectives and quality measures drive the search for alternatives and provide a framework for comparing them. They describe major environmental, social, cultural, economic, or health and safety concerns that may be influenced by alternatives (Gregory et al., 2012). These values and concerns can be easily quantifiable or hard-to-quantify.

2.2.3. Assess system vulnerabilities

Climate change vulnerability depends on system exposure, sensitivity, and adaptability to the projected change (Pachauri et al., 2014). Exposure is the degree to which parts of a climate-sensitive system are exposed to the projected climatic stressors and shocks, whereas sensitivity is the degree to which a system can be affected by such stressors and shocks without adaptation (Pachauri et al., 2014). Adaptive capacity is the ability of a system to adapt to such changes. The goal of the vulnerability assessment is to document the system's major exposure and sensitivity to current and future climate changes. An initial vulnerability assessment helps to conceptually relate climatic stressors to stated objectives, lead subsequent data collection, and guide further development of quantitative models and methods.

The experience and knowledge of managers, experts, and other stakeholders can often be relied on to quickly document possible system vulnerabilities (Ohlson et al., 2005). Examining historical weather variability and extremes may shed light on vulnerability to future climate change scenarios (Ohlson et al., 2005). Expert consultation and simple what-if analysis may also aid in delineating future climate scenarios (Ohlson et al., 2005).

2.2.4. Develop alternatives

Step 4 is about coming up with a good risk management plan that includes planned, proactive measures. This stage aims to propose alternate, internally consistent adaptation strategies that address climate change risks. This step and the evaluation step followed are generally performed iteratively. While some climate change adaptation strategies are relatively simple and straightforward, other alternatives are more complex sets of actions that vary based on different priorities across objectives. SDM helps to develop creative alternatives that are responsive to the established objectives. It emphasizes

discovering and iteratively refining alternatives. It is also critical to look for alternatives that can withstand uncertainties.

2.2.5. Evaluate alternatives

This step evaluates the consequences of the alternatives in achieving the statement objectives based on the performance measures. Simulation modeling or expert judgments, or a combination of the two, are usually the primary methods for obtaining such information. Typically, information is provided collaboratively by experts such as scientists, practitioners, and local or traditional knowledge holders. Trade-offs of various strategies in achieving different objectives and addressing uncertainties should be highlighted to identify strategies that are robust in future climate scenarios. There are many tools and methods to help evaluate the potential outcome and tradeoffs, such as consequence tables, multi-criteria evaluation methods,cost–benefit andcost–effectiveness analyses (Gregory et al., 2012). To better evaluate and compare the alternatives, it is best to include a “base” or "do nothing" option in the analysis. If exist, "no regret" measures, which perform well across all objectives and work well in any future climate, should always be preferred.

It is worth noting that value preferences and risk tolerance may vary across stakeholders and circumstances and need to be considered carefully. Thus, the process of developing and evaluating adaptation strategies should be collaborative and deliberative, involving decision-makers, stakeholders, and experts.

2.2.6. Implement, monitor and review

Finally, after implementing the selected strategies, monitoring and review of the outcome should be performed regularly to make proper adjustments as circumstances change to address uncertainty. Steps 5 and 6 should be an iterative process that incorporates both analytical approaches and organized discussions, allowing for several rounds of plan refinements until an acceptable balance of all consequences is achieved. The findings from the evaluation and review would then be carried forward to better define the problem context, determine objectives, and develop the next round of alternatives.

The whole structured decision-making process should foster learning and strengthen adaptive capability to support better decision-making in future. Whether these learnings pertain to technical understanding of the problem and its solutions, institutional capability, or people resources, competencies, and their value preferences, SDM's capacity to promote reciprocal learning throughout the process is the key to its success.

This project used the structured decision-making framework to collect information from stakeholders in order to gain a better understanding of the key factors that define the first four steps of the planning process, namely the problem context, objectives, vulnerabilities, and alternatives, and influence the last two steps of the process (i.e. evaluation and implementation). The findings lay the groundwork for future studies into more detailed modeling and assessment of adaption options.

CHAPTER 3. METHODOLOGY

3.1. Research Design

This project builds upon the findings of the Year 2 vulnerability study to identify stakeholders' concerns and priorities in anticipation of the projected sea level rise (Shen and Shim, 2021). In addition to the community survey conducted in the Year 2 project, this research collected data through qualitative, in-depth interviews with relevant stakeholders to gather information to understand the challenges, objectives, vulnerability, and adaptation planning process in response to the projected sea level rise. Participants in this research were identified through preliminary interviews with transportation planning experts from the metropolitan planning organization. Through the process, we sought to understand the factors that influence adaptation planning to sea level rise in the transportation sector. Key aspects that we sought to understand were major concerns and priorities, development and evaluation of adaptation plan, stakeholder responsibility and collaboration, difficulty and challenges for implementation, as well as potential conflict and tradeoffs. Figure 3-1 shows the design framework of the interview questions. The interview questions were carefully designed in advance and matched with follow-up questions to elicit more information. Before researchers collected the qualitative data, the Internal Review Board (IRB) examined and approved all interview questions.

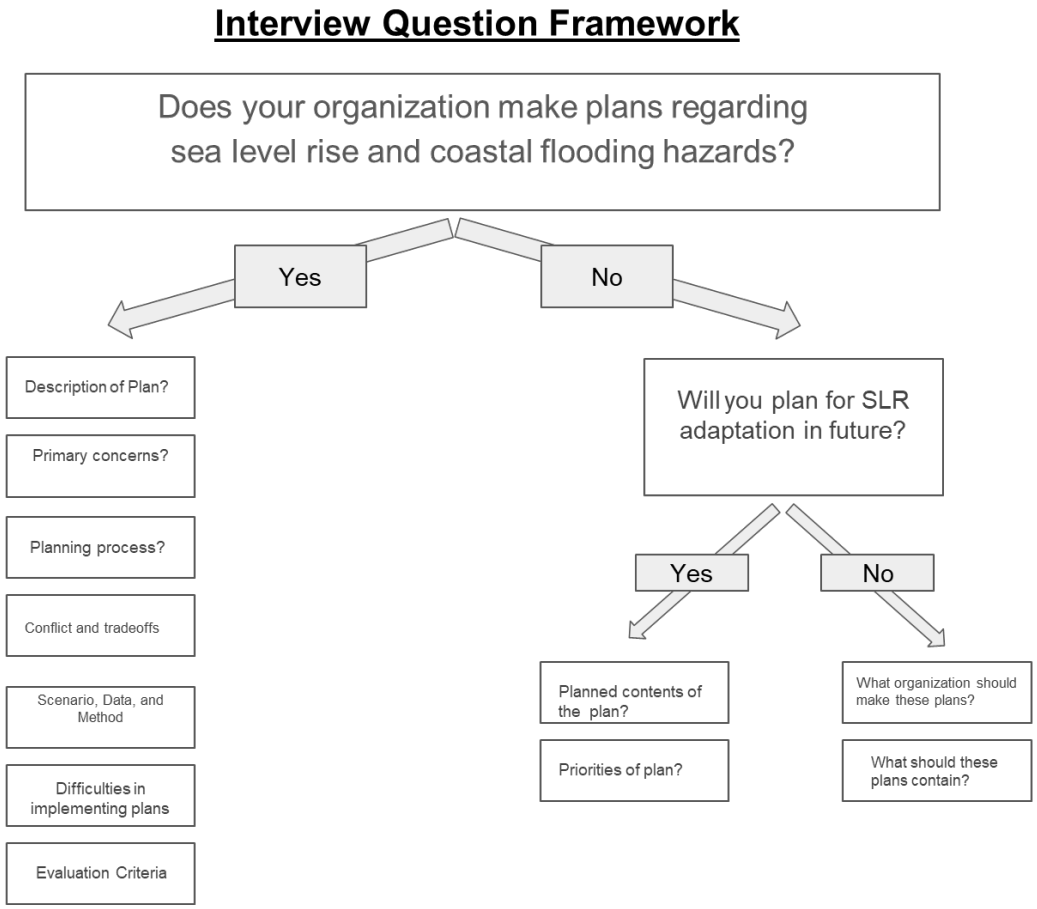

Figure 3. 1. Interview Question Design Framework

3.2. Sampling Methods

To identify essential stakeholders in transportation adaptation planning, a typical case sampling method was used. Researchers used the typical case sample method (Patton, 2002) to identify key adaptation stakeholders by interviewing informants at the regional transportation planning organization. Toward the end of each interview, researchers asked participants to propose other interviewees who understood the topics they had been asked. A total of 29 Stakeholders with various backgrounds were identified, such as State, City and County transportation and operation agencies, facility management, transit agencies, climate scientist, environmental agencies, non-profit organizations, community groups, and private sectors. The majority of the interviewees (i.e. 58%) come from government agencies, 21% come from community groups, and the rest come from academia, non-profit organizations, and private companies. Among all government agencies, about 60% come from the City and County, and 40% comes from the state and regional agencies. In general, responses from a diversified representation of various stakeholders were collected.

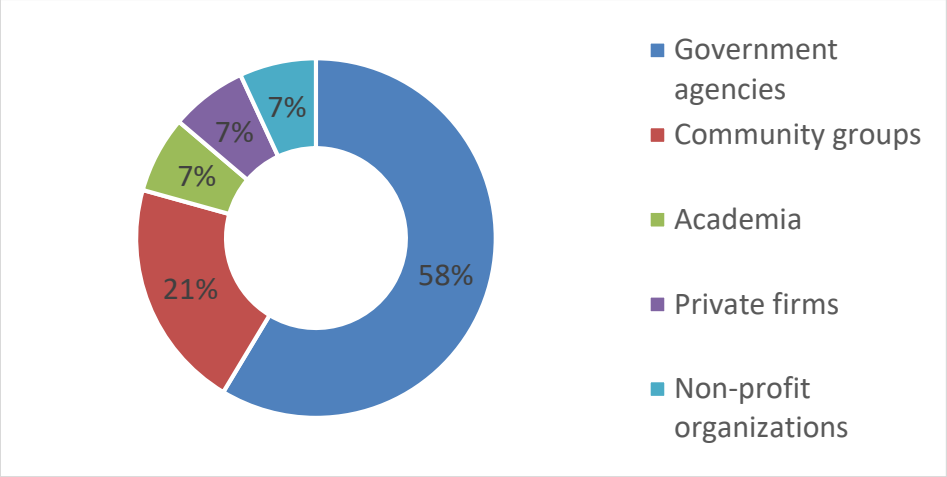

Figure 3. 2. Interviewee Background

3.3. Interview Analysis

All interviews are transcribed into written transcripts for future investigation. Following that, one researcher went through all of the transcriptions to develop a coding scheme. To validate the coding method, two researchers used it to assess the same five transcriptions independently and then compared their results for consistency. Throughout this procedure, the research team deliberated and agreed on category and coding rule definitions. Using the data-driven code (Table 3.1), the transcripts are then analyzed using computer software (i.e., ATLAS.ti) to find the prevalent themes for each of the following areas:

- Problem context
- Planning objectives
- System vulnerability
- Adaptation alternatives
- Planning process

Table 3. 1. Data-Driven Codes

Theme	**Codes**
1. Hazards and Impacts	Existing impacts and future concerns related to transportation adaptation to sea level rise 1-a Hazard scenarios of concern 1-b Existing and potential impacts on transportation 1-c Specific concerns and priorities with the projected change
2. Planning Objectives	Objectives and factors to consider with regard to transportation adaptation to sea level rise
3. System Vulnerability	Factors influence transportation system vulnerability 3-a Physical aspect 3-b Social aspects 3-c Economic aspect
4. Adaptation Evaluation	Key factors for the development and evaluation of adaptation alternatives 4-a Adaptation plan and options 4-b Key elements to include in adaptation plan 4-c Key criteria to evaluate adaptation alternatives
5. Recommendations	5-b Barriers and gaps in current adaptation planning process 5-c Further analysis

CHAPTER 4. FINDINGS

4.1. Problem Context

Throughout the interviews, interviewees are particularly concerned about several types of hazards and their impacts on transportation systems. First, all of the interviewees concur with the scientific consensus that climate change and increasing sea levels are occurring and are concerned about its possible impacts on transportation and how to adapt to such impacts. In addition to direct SLR, one-third of the interviewees are also concerned about the associated coastal erosion, followed by groundwater inundation, high tide, extreme weather events such as hurricanes and storms, coastal flooding, and potential compound hazards.

Along with the commonly acknowledged trend of SLR, associated coastal erosion is also widely recognized as occurring and posing an increasing risk to beaches, land, properties, and roads. The concentration of development in low-lying coastal areas exacerbates such risk. According to a geologist, "[in Hawaii] 70 % of our beaches are eroding or moving back or running into the development of our shoreline…People just build too densely, too close to these hazard prone [areas]" and there are "homeowners who have homes on falling off sand dunes at Sunset beach for example." The North Shore, the east side of the island, the Kamehameha Highway at Laniakea, and Hauʻula to Kaʻaʻawa are just some of the areas of the island that are currently being undermined by erosion. Even without coastal flooding or inundation, the associated shoreline erosion may render certain roadways impassable. Such risk could cause even more problems for communities with no other routes available and depend on the road that is impacted as the only means of transportation. A director from one of the non-profit organizations explained the specific concerns:"It's probably illustrated with situation where the one state highway is already a victim of erosion, and none of the alternatives are very good, and yet it's the only means of transportation through the area."

Groundwater inundation is another highly concerning risk associated with sea level rise. Nine out of 29 respondents are very concerned about groundwater inundation as it could result in a range of problems, such as rising groundwater levels, salinity, and stormwater drainage backflow. Unlike coastal flooding, which may be mitigated through hard structure protection such as sea walls, groundwater inundation could cause back shore flooding in low-lying areas further inland. Furthermore, through salinity and infiltration, groundwater inundation could pose threats to the water supply system, wastewater system, and cesspools; many of these systems are located beneath or near roadways. With the projected sea level rise, a large part of the heavily urbanized area of Honolulu and WaikīkĪ is at risk of groundwater inundation flooding (Habel et al., 2017). With the rising temperature, groundwater inundation may cause more damage to the roadways. As one of the geologists pointed out: "those shallow groundwater levels can cause more damage to roadway then temperature and road combined. I think now in places that are really low-lying and have chronic problems with potholing, like Kapiʻolani Blvd. DOT might need to take extra close look at whether the pot holing is constantly shallow on groundwater table".

Eight of the people who were interviewed voiced concerns about coastal flooding caused by high tides and storms in general as a result of SLR, groundwater inundation, and coastal erosion. Many critical highways are located in low-lying areas and are susceptible to coastal flooding. As one of the neighborhood board members mentioned, "major concerns for myself and my community is our major road way, Farrington highway [is] within hundred yards of ocean and it's susceptible to flooding [even] if

it's not damaged from king tides and higher sea level rise, and it's a major concern for us because it cuts off from commodities and getting assistants."

In addition, respondents were concerned about the possible threat posed by the combination of storms, tropical cyclones, tsunamis, extreme rainfall, and sea level rise. One of the geologists voiced concern on the potential compound hazards: "We haven't really experienced extreme tsunami or hurricane here. That's my biggest worry. That combined with additional sea level rise or with a storm that's being even more extreme with climate change, severing more and more roads." This is echoed by another scientist, who calls for the consideration of compound disasters and cascading effects in planning:

"planning with regard to natural disasters needs to stop looking just at heavy rain events or heat waves or tropical cyclones but needs to look at tropical cyclones that are immediately followed by heat waves or tropical cyclones that cause power failure immediately follows when the heat wave settles in or intense rain events on top of the heat wave. Compound events are with a new reality as climate changes."

Finally, in terms of compound hazards, respondents mentioned extreme heat and flash floods in addition to coastal hazards and extreme events. One planner and two geologists raised concerns about extreme heat and its potential health impacts. One of the geologists mentioned, "North shore Kauaʻi, those are especially concerned with extreme heat and health impacts related to that are very concerning." Because of the potential negative effects on people's health, there may be an increased need for medical care and emergency services. Concerns about emergency access may be compounded in areas that can only be reached by a limited number of roads and are vulnerable to flooding caused by rising sea levels and coastal erosions. In addition, consideration for heavy precipitation and flash flood in adaptation is mentioned by three planners and one geologist. As one of the experts says: "[For adaptation] Next one is low impact development. It's not really sea level rise. It has to do more with climate change in general. If there is a 100-year storm, how do we become more resilient?"

In summary, the findings from the interview match the findings from the Year 2 research in that, in addition to direct inundation from sea level rise, experts and community members are concerned about coastal erosion, groundwater inundation, storm surge, and coastal flooding. Furthermore, the experts questioned stressed the significance of preparing for other climate change consequences, such as excessive heat and flash floods, in addition to SLR and coastal risks.

4.2. Planning Objectives

In preparation for the projected sea level rise, the City and County of Honolulu and the State of Hawaiʻi have started a series of vulnerability studies and adaptation planning initiatives in various government agencies. Mayor Kirk Caldwell of the City and County of Honolulu issued Mayoral Directive No. 18-2 in June 2018, emphasizing the importance of addressing the projected impacts of SLR on Oʻahu (Office of the Mayor, 2018). The directive instructs all departments and agencies in the executive branch to "consider the need for both climate change mitigation and adaptation as pressing and urgent matters, to take a proactive approach in both reducing greenhouse gas emissions and adapting to impacts caused by sea level rise, and to align programs wherever possible to help protect and prepare the infrastructure, assets, and citizens of the City for the physical and economic impacts of climate change." It requires that city departments and agencies use the Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report and the City and County of Honolulu Climate Change Commission Sea Level Rise

Guidance for baseline planning, infrastructure and development evaluation, evaluating climate change adaptation strategies and implementation. Eleven of the respondents interviewed mentioned, in accordance with the Mayor's Directive, that they are utilizing the exposure area of 3.2 feet of SLR as a benchmark for adaptation planning and 6 feet of sea level rise for the planning of critical infrastructure with long expected lifespans and low-risk tolerance.

With regard to adaptation planning objectives, most planners interviewed underlined the significance of increasing resilience under the projected 3.2 feet SLR scenario. Although transportation infrastructure is the primary emphasis of the interview, many of the interviewees believe that increasing transportation resilience could not be achieved without a broad objective that includes resilience not only for transportation infrastructure but also for other relevant utilities, land use development, and conservation. A coastal geologist, for example, stated that

“Since the coastal line with sea level rise is expected to rise, any kind of critical infrastructures are planned in those locations and have life expectancy with sea level rise to impact … then we could make guidance on that type of planning… or if it’s on conservation land, we might ask them to include sea level rise in their planning”.

On a macro level, transportation resilience is intricately intertwined with the resilience of land use development. A transportation planner expressed his concerns for the continued development in vulnerable neighborhoods “some of my concerns are regarding the transportation facilities and their effect on land use. Very concerned for the north shore and Waianae coast because people are building on those communities based on the assumption that they can always get there in two directions going around Haleiwa or Kaneohe connect whole [loop]. Substantial with billions of dollars, I don’t think that that’s a realistic probability. I think that there are going to be segments on those corridors that we may not be able to afford to have.[In future] I think they are going to be falling off the ocean, and without gigantic invest of money, the roads are not going to be around anymore.” Five respondents voiced their concerns about the vulnerability of ongoing transit-oriented development (TOD) along the rail to sea level rise and the associated coastal hazards. For instance, in the words of a planner, “Along the 20-mile alignments, there are several communities that are close to the shore. These communities, some of the locations where rail stations are located, may potentially be affected by different aspects of sea level rise and coastal flooding. Depending on the timing, depending on the year, and depending on the storm, and wave conditions, there are different potential scenarios for area flooding and indoor inundation. Essentially about the locations of our rail facilities and the surrounding area development around the rail alignment”. To strengthen the resilience of the rail system and surrounding development, a planner emphasized that “It’s important for us to promote resilience when new development comes in. That’s true for housing or high rise, [or] anything that comes in, also [also] true for infrastructure projects”. Another planner pointed out the concerns of the zone change for higher density development in vulnerable zones: “zone changes, a lot of areas were involved with rails, increasing density, typical TOD vision. Obviously, that vision doesn’t include being inundated by water. Every time I have to explain this to people, I get frustrated because the rail alignment is so close to the ocean. … I support TOD… obviously, but I also support not building big buildings in an inundated area.” Other planners advised analyzing the vulnerability of transportation systems to sea level rise in light of diverse land use development scenarios: “We should have development scenarios so people can clearly see the effects of land use decisions. Traditionally, we only have one land use scenario, whatever was right development. I

think TOD scenario, showing the pros and cons impacts of sea level rise on transportation planning between those TOD scenario and business really would be helpful."

At the facility level, the resilience of relevant utilities is also essential to maintaining the transportation system's performance. As mentioned by several planners, the critical facilities are "like mechanical rooms, electrical utilities, equipment and things like that" or "buried infrastructure underneath the road" such as "sewage lines, fresh water lines." A planner underlined the importance of building more resilient power supplies for the planned rail stations "[It is important to] build the future station from airport to city to include measures where some of their [i.e., future rail station] critical infrastructures are not above the certain level. If it does get flooded, it touches their generator or important stuff".

In addition to strengthening infrastructure and development resilience, consistency with other planning objectives and community benefits is also frequently mentioned. Walkability, livability, transit accessibility, housing affordability, environmental issues, and cultural concerns are some aspects that interviewees suggest taking into account in transportation adaptation decision-making. For example, a planner suggests providing design guidelines with regard to elevating the buildings and roads to make sure walkability is not affected by sea level rise adaptation measures. Other measures that can aid in adapting to climate change and achieving multimodal goals, such as street trees and landscaping that encourage walkability and minimize urban heat, should be prioritized in implementation. Another planner stressed the importance of aligning the planned flood control projects and street widening projects with climate adaptation to make them not only more resilient but also more livable and walkable. Finally, as one of the scientists pointed out, "different sorts of socio-economic, cultural aspects" as well as potential environmental impacts all need to be weighted in with regard to adaptation.

In summary, while focusing on transportation adaptation planning to sea level rise, the interviewees advocate for a broader, more comprehensive view of the climate problems as well as embracing a holistic set of objectives in addition to transportation infrastructure resilience. They recommend that transportation adaptation should be planned in conjunction with current projects and other activities that are aimed at addressing sustainability, livability, affordability, cultural, and environmental concerns and call for more consolidated efforts through a leading agency. Coordination between multiple agencies and jurisdictions is needed to build such holistic resilience. For example, in a scientist's words, "You got agencies at different jurisdictions at the city level, at the state level, and different offices within those jurisdictions. They all need to be brought together to figure out how to deal with the road with sea level rise."

4.3. System Vulnerability

While the physical susceptibility of transportation infrastructure to sea level rise is obvious and has been identified in previous studies (e.g., Shen and Kim, 2020), there is a need for a better understanding of system vulnerability beyond physical exposure. Through interviews, we identified the physical, economic, social, and institutional factors that influence the transportation system's vulnerability to SLR.

One-third of the interviewees identified the physical aspect as a significant factor that contributes to system vulnerability. The identified physical factors include Hawai'i's distinct geographical and geological characteristics, infrastructure placement and locations, and the inherent interdependency of infrastructure systems. Because of Hawai'i's unique island geography, there is a concentration of development and infrastructure, including transportation corridors in areas extremely close to the ocean. Sea level rise could multiply climatic hazards such as storms, tsunamis, or hurricanes in the highly dynamic shoreline environment. System vulnerability will be exacerbated by exposure to compound hazards and the cascading effects. As a scientist put forward that "compound events are with a new

reality as climate changes" and "planning with regard to natural disaster needs to stop looking just at heavy rain events or heat waves or tropical cyclones but need to look at tropical cyclones that are immediately followed by heat waves or tropical cyclones that cause power failure immediately follows when the heat wave settles in or intense rain events on top of the heat wave." When combined with other distinct geological conditions, such as porous limestone and seasonal high wave energy, it makes the infrastructures and properties more vulnerable to coastal hazards and makes some adaptation measures utilized in other parts of the world (e.g., seawalls) less effective. Several planners and geologists have expressed concern about the highly dynamic shoreline environment, as well as the fact that some low-lying areas with high-density development were originally wetlands that were artificially filled in the early twentieth century and are only two feet above high tide groundwater. Without appropriate adaptation measures, the existing high-density construction and the planned high-density transit-oriented development in these low-lying areas could add to such vulnerability. With regards to transportation infrastructure, in particular, certain characteristics make them especially vulnerable to SLR and compound hazards. In addition to being close to the coast, because of the restricted island terrain, certain communities just have one road connection and no alternative roads if the only road in and out is being undermined. The lack of a road shoulder on these critical links could exacerbate the situation for transit riders. Lastly, due to the inherent interdependence between infrastructure systems, the vulnerability in other critical infrastructures, such as hurricane and climatic hazards' effects on power supplies, electrical generators, and infiltration and inundation to sewer pipelines under the roads, could all make the transportation system vulnerable and should be considered holistically. As a scientist pointed out

"This means that not only the department of infrastructure [dealing] with the drainage, department of transportation [responsible for] the roadbeds, Department of environmental services with sewage treatment but [also] communications department, or communication agencies like the emergency services [are all vulnerable]. You cannot get an ambulance through this [i.e., community with only one road that is undermined]. You can't get a fire truck through that. Hospitals need to be made aware of situations like this... If there is a house on fire, you can't bring a fire truck. Someone has a heart attack. You cannot bring in an ambulance."

Another frequently discussed factor that influences system vulnerability is the economic limitation. One-third of the interviewees mentioned "budget and funding" as one of the most critical and challenging issues. Many participants concur that adaptation may be highly costly and that it may be challenging to acquire funds for it, not just for the adaptation measure itself but also for the staff needed to develop adaptable capacity. Especially such funding may have to compete with other more pressing priorities, which could make the agreement on how to use the funding hard to achieve among stakeholders. Equity issues related to the fund's spatial distribution, such as who pays and who receives, could also come up throughout this process. For example, a planner mentioned questions such as "do we make the [inundated] area pay for it, or does the whole county take on the financial responsibility of that one area" could arise, and issues such as equity, fairness, and incentives for adaptation must all be factored into the discussion. Furthermore, it may be out of property owners and local governments' capacity to raise enough funds. External support, such as from the federal government and private parties, is also cited as essential. Funding may be allocated to distinct silos, departments, and domains. Collaboration is vital for reducing redundant and even conflicting efforts. Depending on where the money originates from, it may take a long time to obtain and have different funding cycles, which, if not adequately coordinated, can have a substantial effect on the timing of action and the ability to adapt. As a result, in order to reduce the system's vulnerability, it is essential to develop a strategic funding plan outlining all prospective funding sources, spatial scales, and timing of actions to identify potential overlaps and conflicts.

Related to the previously mentioned equity issues in funding allocation, participants brought up several concerns from a social perspective. The necessity for prioritizing the adaptation planning process is the first concern. Eleven participants stressed the importance of prioritizing funding based on vulnerability and criticality. For example, planners and program coordinators underline the importance of developing a procedure to answer questions such as “how to prioritize vulnerability” and “how to clearly define critical infrastructure? what is important?”. The discussion of prioritization not only needs to take into account physical exposure and facility criticality but also needs to be in line with expected future growth, ongoing and planned efforts in other departments, as well as communities’ needs. Again, the ranking of potential competing priorities and the appropriate balance between them must be carefully evaluated. As a coastal geologist pointed out that sometimes we need to consider the hard question “what we value the most,” for example, between “public beach” and “private property” if we can not protect both. Another planner said land use decisions like whether to “keep the development” or “move that function” are important for answering questions about whether the roads leading to these areas “[are] really needed to protect.” Prioritization also needs to align with the broad goals of community vision, like, sustainability, public safety, multimodal access, and equity, and as a transportation planner suggests “ projects that meet multiple concerns or desires of the community would be ranked on top, so ideally projects that improve safety, improves multimodal options, improves resilience in transportation system … get ranked first.”

Finally, working in silos has been frequently mentioned as another factor contributing to system vulnerability. As we mentioned above, SLR and the associated climatic hazards have caused problems not only in transportation infrastructures but multiple sectors related to transportation. Adaptations to these problems need to take into account a variety of perspectives from various agencies. While different sectors and agencies are planning or taking adaptation actions, many interviewees are concerned that working in silos without appropriate communication and coordination would undermine the efficiency and effectiveness of adaptation. Problems could occur when there is a lack of communication. As a planner said, “a lot of groups are working on different plans and studies, but people don’t necessarily know what’s all available.” Without coordination, inconsistencies between plans could happen, such as “ different agencies are on different pages in terms of sea level rise. Some people are using SLR-XA that’s produced by OCCSR, some people are using nationals like NOAA”. A scientist criticizes such a situation as “operating in silos, a lack of communication, a lack of broad-based intergovernmental strategic planning” and calls for “an overarching climate change-oriented entity” at both the city level and the state level with an appropriate level of authority and capacity to perform vulnerability and adaptation analysis and screen projects to ensure consistency.

4.4. Adaptation Plans and Options

In recent years, many plans have been developed with a consideration of SLR adaptation in the study area. Table 4.1 provides a list of recent reports and the plans mentioned by the interviewees.

Table 4. 1. Existing Adaptation Plans and Reports

Plan	Regions	Agency/Organizational affiliation	Date	Description
Annual Sustainability Report	C&C	Office of Climate Change, Sustainability and Resiliency	2022	It tracks specific measures and indicators from activities across O‘ahu that focus on climate change, sustainability, and resiliency
Primary Urban Center Development Plan	City and County of Honolulu	Department of Planning and Permitting	Updating: Public Draft 05/2022	Latest update Focus the majority of future growth near transit and daily services, and invest in bus transit-supportive corridors.
Act 178 Relating to Sea Level Rise Adaptation: 2021 Annual Report	State	Hawai‘i Office of Planning and Sustainable Development & the Hawai‘i Department of Business, Economic Development and Tourism	12/2021	It summarizes the state facilities located within each of the five analyzed sea level rise scenarios by island.
Risks of Sea Level Rise and Increased Flooding on Known Chemical Contamination in Hawaii	State	STATE OF HAWAII DEPARTMENT OF HEALTH	06/2021	It discusses the potential environmental concerns posed by anticipated increased flooding, groundwater inundation, and disruption of contaminated lands in coastal areas due to climate change and rising sea levels
Hawaii Highways Climate Adaptation Action Plan: Strategies for a More Resilient Future (2021)	State	Hawai‘i Department of Transportation Highways Division	05/2021	It outlines the potential threat of climate change to Hawai‘i Highways
Hawaii Highways Climate Adaptation Action Plan: Exposure Assessments (2021)	State	Hawai‘i Department of Transportation Highways Division	04/2021	It provides a comprehensive exposure assessment of highway assets that are at risk of a variety of climate-related hazards and lava flow hazards.
Nature-Based Resilience and Adaptation to Climate Change in Hawai‘i: A	State	Hawai‘i Climate Change Mitigation and Adaptation Commission	03/21	This paper highlights actions in Hawai‘i that rely on nature-based “green-blue” strategies to adapt to and mitigate

Plan	Regions	Agency/Organizational affiliation	Date	Description
Climate Ready Hawai'i Working Paper (2021)				climate change
Guidance for Using the Sea Level Rise Exposure Area in Local Planning and Permitting Decisions (2020)	State and County of Honolulu	Hawai'i Climate Change Mitigation and Adaptation Commission and University of Hawai'i Sea Grant College Program	10/2020	It assists state and county planners, natural resource and infrastructure managers, and others with understanding and using the Sea Level Rise Exposure Area (SLR-XA).
Guidance for Addressing Sea Level Rise in Community Planning in Hawai'i (2020)	State	University of Hawai'i Sea Grant College Program and State of Hawai'i Department of Land and Natural Resources and Office of Planning	04/2020	The paper develops plans and pre-disaster recovery frameworks at the county level that incorporate opportunities to adapt to sea level rise.
Hawaii Ocean Resource Management Plan	State	Office of Planning	Updating	The plan seeks to foster collaboration among agencies with ocean and coastal resource management responsibilities through three focus areas: Development and Coastal Hazards, Land-Based Pollution, and Marine Ecosystems
Oahu Watershed Management Plan	C&C	Board of Water Supply	2020	Guidance for the sustainable management of watersheds, protection, and enhancing water quality and quantity.
Preliminary Climate Adaptation Guidelines	C&C	Department of Transportation Services – Transit-Oriented Development	2020	Guidance to develop preliminary climate resilience that can be used by developers and landowners in Honolulu transit-oriented development (TOD) and other urban areas that may be vulnerable to sea level rise (SLR).
State of Hawai'i Statewide Coastal Highway Program Report (2019)	State	State of Hawaii Department of Transportation, Highways Division	08/2019	To develop a methodology that assesses and ranks the susceptibility of Hawaii's coastal roads to erosion and structural degradation due to ocean hazards such as waves, currents, tides, and sea level rise
Guidance for Disaster Recovery Preparedness in	State	Department of Land and Natural Resources and Office of Planning	07/2019	It will improve the governance structure for recovery functions by identifying pathways to pursue critical disaster recovery preparedness activities to support resilient

Plan	Regions	Agency/Organizational affiliation	Date	Description
Hawai'i (2019)				recovery and reconstruction
Assessing the Feasibility and Implications of Managed Retreat Strategies For Vulnerable Coastal Areas in Hawai'i: Final Report (2019)	State	Office of Planning, Coastal Zone Management Program	02/2019	This assessment examines managed retreat programs that have been successfully implemented in post-catastrophic events and in response to chronic coastal hazards.
Oahu Resilience Strategy	C&C	Office of Climate Change, Sustainability and Resiliency	2019	List of an action plans directly address the challenge of long-term affordability and the impacts of a climate crisis that is already driving islanders from their homes.
Assessing the feasibility and implications of managed retreat strategies for vulnerable coastal areas in Hawaii	State	Office of Planning – Coastal Zone Management	2019	Assess Feasibility and Implication Managed Retreat Strategies for Vulnerable Coastal Areas in Hawai'i
Hawai'i Sea Level Rise Vulnerability and Adaptation Report (2017)	State	Department of Land and Natural Resources	Updated 11/2018	It is a first state-wide assessment of Hawaii's vulnerability to sea level rise and recommendations to reduce exposure and sensitivity to sea level rise and increase capacity to adapt
2018 State of Hawai'i Hazard Mitigation Plan (2018)	State	For Hawai'i Emergency Management Agency by Tetra Tech	10/2018	It stresses an integrated, multi-level, multi-sector, collaborative approach to risk reduction with an emphasis on building community resilience.
Hawaii Coastal Erosion Management Plan	State	Department of Land and Natural Resources	2013	The Objective is to outline socioeconomic and technical mechanisms for conserving and restoring Hawaii's beaches in a framework of mitigating erosion impacts and reducing exposure to coastal hazards for future generations.

The adaptation strategies identified in these reports and plans can be classified generally into three categories: 1) accommodation, whereby adjustments are made to the current system to changing natural conditions (e.g., strengthening flood-proofing regulations or sand-dune replenishment); 2) protection, involves the hardening of a system in its location to withstand the impacts of changing conditions (e.g., use of sea-walls for shoreline hardening); and 3) retreat, relocating structures to avoid impacts (e.g., tax incentives for relocation, shoreline construction setback) (Codiga and Wager 2011).

In 2019, the Department of Planning and Permitting (DPP) from the City and County of Honolulu held pop-up workshops for the residents of the primary urban center to share information about the existing impacts of SLR in the primary urban center area and to identify the needs and desires of the public regarding the various SLR adaptation strategies in Hawaii. At the workshops, the planners from DPP identified the following typical adaptation strategies:

- Potential In-Land Adaptation Strategies
    - Restrict new development
    - Require district drainage
    - Raise roads and pipes
    - Raise/abandon/repurpose 1st floor
    - Rapid retreat (phased over 30 years)
    - Slow retreat (phased over 60 years)
    - Adaptive design requirements
    - Floodable park
- Potential Coastal Adaptation Strategies
    - Sea wall/revetment
    - Riprap rock armor
    - Natural or living shoreline
    - Sand nourishment

Out of the workshop, the residents of the primary urban center helped to identify the following SLR adaptation strategies as the top priority for the urban center:

1. Low-impact development (LID) projects
2. Resilient building design guidelines/standards
3. Development restrictions tied to triggers
4. Pausing bonus density in impacted areas
5. Resilient infrastructure
6. Incentivized retreat
7. New adaptation funding
8. Private sea walls

However, despite these efforts, there is a lack of understanding of people's perception of the risk, the underlying factors in adaptation preference, and the lack of a consistent overarching framework for assessment with regard to transportation-related adaptation. Transportation adaptations are especially important given the potential impacts of transportation decisions on future development patterns, and the ability of coastal regions to adapt to climate change may be aided or hindered by decisions made by transportation officials today (Titus, 2002). Protecting transportation infrastructures from the projected climatic hazards would be costly. Given the great uncertainty in future scenarios, planners need to develop plans that are more flexible and adaptable (Asadabadi,

2017). Parris et al. (2012) advise using a range of scenarios to avoid locking into one specific scenario and the potential loss of vulnerable assets in other scenarios.

To understand people's perception of the risk and their adaptation preference with regards to transportation, in CSET Year 2 project (Shen and Shim, 2021) , we asked the participants if they think that sea level rise will increase the frequency of coastal flooding and whether they are concerned about frequent coastal flooding affecting their travel in future. More than 80 percent of respondents answered yes to both questions, expressing concerns that the rising sea levels cause more coastal flooding and that the increased frequency of coastal flooding will affect even more travel in the future. In general, younger people, females, and people who live in urban areas are more likely to have the perspective that SLR will increase coastal flooding and are concerned about the potential impacts of coastal flooding on travel. Despite the fact that the majority of the respondents are concerned with SLR impacts on future travel, half of the respondents think the impacts of coastal flooding and SLR could be self-manageable. The survey results show that people who live in urban areas are more likely to have a perspective that SLR is self-manageable than people who live in rural or suburban areas. More people with lower incomes think that SLR is more manageable than people with higher incomes. More males believe SLR is manageable than females.

This community survey also gathers the community's suggestions for transportation-related adaptation strategies for future SLR. Community members suggested stopping construction in flood zones as their most frequently mentioned adaptation options when asked how to adapt to recurrent coastal floods. O'ahu has a large number of houses along the coast, and retreating them can be time- and money-consuming. Therefore, stopping development in flooding zones makes sense among the community members. The second most frequent answer was the maintenance of drainage systems and coastal roads. Some people also mentioned elevating roadways further inland. It was also suggested that more trees be planted as part of green infrastructure for stormwater management and that the community, business sector, and government agencies be involved in the early stages of the planning process. Overall, people urge to develop a long-term plan to support efforts against SLR sooner rather than later.

To better understand the underlying factors in adaptation preference so as to develop a consistent framework for assessment, we asked the 29 interviewees about transportation adaptation-related concerns, key adaptation plan elements, and evaluation criteria. With regards to the adaptation options, interviewees mentioned a list of potential adaptation options similar to those identified in previous studies, including, for example, hard structure protection options such as engineered beach, seawall, flood control system, rock riprap, elevated ground floor and roads, accommodation strategies such as green infrastructure, low impact development, stream de-channelization, reduce impervious surface, street trees, and pre-disaster recovery plan development, and retreat options such as restricting new development through set back, restrictive zoning, special management area permit and managed retreat. Raising roads (17%), seawalls (14%), and managed retreats (17%) are the most frequently mentioned adaptation alternatives with regard to transportation. There are concerns regarding the potential implications of these adaptation alternatives, which must be carefully planned, and we will elaborate on these concerns further below.

4.5. Adaptation Plan Key Elements

The interviewees brought up a number of important considerations in transportation adaptation and helped to identify a list of critical elements for adaptation plan development. The most frequently mentioned elements by the interviewees are the timing of action (31%), prioritization (38%), stakeholder identification (31%), community engagement (38%), budget and funding (31%), and

holistic view (14%) . Many interviewees believe that a good adaptation plan should "look at everything holistically" and "[not] consider sea level rise as a silo." The consideration of transportation adaptation cannot be limited to transportation issues. Cross-sector strategic planning is needed to take a holistic view. As one scientist put forward, "strategic plans should involve multi-agency, multi-jurisdictional thinking, and sharing."

Stakeholder identification and community engagement is the key to developing an inclusive, holistic view. As a planner said, "it is important to know who the different groups or stakeholders will be involved or impacted." In addition to transportation agencies (e.g., highway, harbor, airport, transit, etc.), interviewees identified a broad list of stakeholders to be engaged in the transportation adaptation process, including but not limited to the planning department, environmental agencies, emergency management agencies, community association, neighborhood board, private consultant and engineering firms. Several interviewees mentioned that we need a lot of community outreach and engagement, especially from the initial stage. From an agency administrator's perspective, "Anything is easier to implement when you have community support. The best scenario is that we are able to have ongoing discussions, workshops, and reports so that people can understand scientific issues and good communications". From a community leader's perspective, it is emphasized that "public information and public awareness are the most important form because if you don't get public input where they don't know what the plans are in place. It is critical public information is accurate and timely incorrect". However, some interviewees did raise concerns about challenges to attract more participation and elicit meaningful feedback in the engagement process. For example, questions such as how to attract people to attend public hearings and engagement meetings, how to foster more constructive discussions, and how to ensure the decision process is inclusive and incorporates diverse opinions all need to be investigated further. Lessons can be learned from the current practice across different sectors. Several interviewees mentioned some good practices from local planning agencies, resilience agencies, science extension organizations, and others. For example, one of the academic interviewees mentioned that they did a lot of inviting and talks in community workshops and meetings as the technical advisor to support the development of community plans. Several local government planning and resilience agencies have also been recognized by multiple interviewees for their great community outreach in developing resilience plan and long-range plans. Innovative formats, such as pop-up poster displays with participatory stickers at community markets and gathering areas, as well as an interactive annual climate change conference, have reportedly received positive feedback. However, common challenges, such as how to ensure a diversity of engagement from the initial stage instead of the same group of people or protests until the construction stage, are key issues to resolve. As a planner said, "ongoing discussions, workshops, and reports that [can help] people to understand scientific issues and good communications" are much needed.

The timing of actions is another crucial component of holistic planning. The planning timeframe should be coherent with the climate prediction timeframe in order to choose potential adaptation scenarios that cover the life cycle of the infrastructure. Regarding rail stations, for instance, a planner at a transit agency noted, "we [must] use the best available information to accommodate what we think the more likely scenarios over the next 50 or 100 years". The time required for planning and construction must also be factored into the planning timeframe. As stated by a community representative, "H3 construction took 30 years from planning to completion. I would [think] for our road it will take a similar time period". In addition, there could be different planning timeframes between adjacent transportation infrastructures and interconnected utilities and land use development.

Coordination is essential to ensure that these planned adaptation actions with varying timeframes are consistent. The actions of one sector may depend on how the other sector adapts, and a lack of planning or coordination in one area may have a domino effect throughout the system. For example, as an agency director mentioned, “[in the past] we really didn't move forward on any of the improvements that were necessary for the shoreline erosion portion mainly because we didn't know which portions of roads would stay and which one we have to move, so we’ve started pushing forward two years ago on a resilience plan…[and] working with UH to prioritize our system to see where the effects are now and how we protect the roads now to ensure that we can get to the mid-century without losing any roads. That gives us the time to start planning out on which portions of the roads have to be relocated, which portions could be elevated, and which portion may not be necessary for the future land use scheme”. It also does not make sense to retrofit or elevate the road for a longer time if the surrounding communities decide to retreat. Similarly, coordination is the key to ensuring the adaptations of interdependent utilities are consistent with the transportation adaption and future development patterns. Finally, given the long time frame of climate projections and the associated uncertainty, it is equally vital to identify what we can do more immediately, in the short term and mid-term, that can increase system resilience. The actions in the near term need to be coordinated with the actions planned in the longer term to ensure strategic planning in phases. The near-term and mid-term plans need to be flexible and adaptable in order to easily handle changing circumstances in subsequent phases. In a planner’s words, “you also have to be realistic in terms of phasing in any adaptation methodologies too early on. Rather than doing it now, you consider it. [We need to consider] how do you plan something so that we could raise the protection or adaptation over time to a 6ft scenario?”

Another critical component of adaption planning is to identify potential budget and funding strategies. Interviewees commonly expressed concerns about the potentially high cost and the source of funding. Questions like “how do you fund those” are frequently brought up. As an environmental planner put forward, “I think just general difficulty would be finding the funding to do it, making sure you have the funding and personnel to have that capacity with your office.” This challenge could be exacerbated by the competition with other more pressing concerns. An expert on coastal management stated, “Unfortunately, a lot of this does come back to money, so you might ask agencies how they are planning to raise funds to adopt things, how that compete with their other priorities.” Developing cost-effective techniques that are multifunctional and can serve several demands and objectives would be critical in overcoming such challenges. In this process, decisions need to consider challenging questions such as how to protect the vulnerable population without making them more vulnerable in the future and how to provide incentives for risk reduction in an equitable way. For instance, a planner provided the following example of when things become complicated” “This one is suggesting if you are living in the area, like Mapunapuna, which is already inundated. We are investing a lot of money in this area. Do we make the area pay for it, or does the whole county take on the financial responsibility of that one area? A lot of people were saying in terms of equity. They were saying It’s not equitable because low-income people usually live in those areas, but it is a way of incentivizing people to move out of those areas, which we should’ve been doing. This is what we’ve been asking the public. Through this discussion, we’ve been gathering information about how things were.” Careful consideration must be given to identifying the priorities, resolving potential conflicts and disagreements, and ensuring equity in obtaining and allocating the funding. The balance between hard structure protection and incentives to reduce long-term vulnerability and between current accommodation and managed retreat in the long term needs to be deliberated carefully. As stated by a neighborhood board representative, “a successful

plan would have a way of funding. So that would be the first thing. You have to pay for it. They have to have consensus with all the stakeholders".

Finally, prioritization is an additional vital aspect of adaptation planning because of the anticipated high costs and restricted funding availability. Assessment and prioritization of system vulnerability would be the first step. A recurring question that was brought up by several interviewees is, "how do you prioritize those vulnerabilities." The localized study needs to be carried out to understand the physical, economic, and social vulnerability in the region and identify vulnerable areas for prioritization. "there might be an opportunity to study particularly vulnerable areas and identify particular areas that might be most vulnerable, and that might be priorities to address first" A planner said. Such vulnerability assessment and prioritization should also be contextualized as a community's vulnerability differs depending on the types of climatic risks and impacts. Particularly for transportation systems, communities far away from physically exposed areas may be substantially influenced depending on the types of accessibility. A holistic view is needed not only across sectors but also across regions. According to a coastal management expert, "we also should start thinking about things regionally, bigger than parcel by parcel, which is part of the challenge right now for adaptation because one parcel owner is a private owner or a government owner. It's very challenging to make adaptations by yourself without having your neighbor do it as well." In the process, environmental implications should also be considered. As a transportation planner said, "They looked at the roads that are most vulnerable to sea level rise, and they prioritize the list of projects, and they see what's the fixes going to be so enhanced, lift the road up, sort of things. There was a suggestion to add additional points for projects that offer positive environmental impacts". With a holistic view, it is then essential to engage stakeholders to identify priorities, such as growth areas, and to create consensus on the common goals, objectives, and values. A planner suggested that developing scenarios could be a good starting point for discussion: "I don't think we can do it all over the city, so maybe from an urban planning perspective, we have to come up with some scenarios, where do we raise the street or where do we not raise the street? That would start a conversation on where are the priority growth areas and where areas are that we really need to invest for resilience". It is crucial to establish the priority in goals, objectives, and values, especially considering the difficulties faced by many stakeholders in balancing various competing priorities. One example is the potential conflict between hard structure protection for private property and the preservation of public beaches raised by a coastal geologist: "I think we believe we think about what we value the most, public beach, private property. We cannot have both. To preserve private property with coastal hardening, so we need to make that decision as soon as possible. So that policy and planning can be conducted that kind of thinking." For transportation systems, it is critical to understand which sorts of accessibility are most appreciated by different communities. In a coastal management expert's words, "The challenge is that these agencies, decision-makers, and politicians are balancing so many different competing priorities. Financial is a primary one. When it comes to climate adaptation, it's going to be expensive. Or transportation agencies, they have their limited budget. Just one example, of course, but they have their limited budget, very difficult job many thousands of miles to maintain both on the ocean where I'm concerned about [coastal areas] but also inland, public safety is their first concern for them".

After identifying the priorities, clarifying criticality would be the next step. This is important to identify the types of facilities and ways to reach the goals and objectives. From the perspectives of implementation and day-to-day operation perspective, people need to have clear definitions of critical infrastructures. Some questions posed by multiple interviewees are "what is a critical infrastructure? And that's not so specifically defined. Is the canal a critical infrastructure? Or is that bridge that goes over the canal a critical infrastructure? What is important?". Besides facility

criticality, coordination with the future land use development plan is also crucial for transportation adaptation. We must consider whether hard structural protection is the most effective strategy to reduce long-term vulnerability or whether there are other alternatives. The goal is not to defend the facility itself but rather to protect the people who utilize the facility. For example, a planner commented, “You may decide that it is critical, but rather than we build and replace, we [could] move that function. [There should be] more conversation on HDOT and state funds [about] rather than continue building that model, move that development.” Various forms of land and resources utilization should be assessed. A planner remarked, “perhaps a more vulnerable program should be a little bit higher, and then you don’t mind flooding the parking in case of emergency because you are not going to kill anybody.” Again, the significance of multifunctionality is emphasized. A transportation planner stated, “We hope that by prioritizing projects based on what public concerns are including sea level rise and flooding. That projects that meet multiple concerns or desires of the community would be ranked on top, so ideally, this project that improves safety, improves multimodal options for folks, improves resilience in transportation system”.

4.6. Adaptation Evaluation

Even though the development of transportation adaptation plans is still in progress, the interviewees did raise some crucial points that should be taken into account when assessing transportation adaptation alternatives. Evaluation criteria and factors that were most commonly indicated by interviewers included feasibility (17%), cost and benefit analysis (14%), community acceptance (14%), and continuing to monitor effectiveness (17%).

As a successful plan must be implementable, implementation feasibility is a crucial criterion for evaluating adaptation alternatives. One of the important questions raised by interviewees is how to include scientific data and up-to-date knowledge in sector-specific and project-level adaptation implementation. “The challenge that we are meeting right now is how to consider this data for particular sectors and infrastructure, like roads and highways, for example. And down to the project property level scale. We need to move from this community-level scale down to like infrastructure, property, project level scale. There is a lot of work still being done on how to consider this data at that level,” said a coastal management specialist. A scientist echoes such challenges and suggests assessing currently planned projects, such as capital improvement projects, for climate resilience. He brought up questions like “To what degree have they moved beyond studies and assessment to the actual moving ground to actual construction projects? Capital Improvement Projects, are they spending large budgets on building resilience and sustainability? That’s the ultimate task, I think. Are they carefully assessing the results of their projects and making adjustments for future projects?”. Iterative adjustments and evaluations should be made to the plan formulation and implementation. “You also have to be realistic in terms of phasing in any adaptation methodologies too early on.” A planner stated: “Rather than doing it now, you consider it. How do you plan something so that we could raise the protection or adaptation over time to a 6ft scenario? Because it would not be very good for our use of public space if we were to build a 12ft wall now. Everybody will be staring at walls and canal on the other side.” Implementation challenges and time frames must be examined repeatedly in this process.

Cost-benefit is another important consideration. Adaptation strategies, according to interviewees, should have a realistic and affordable budget. To reduce the cost many adaptation alternatives should be examined in conjunction with existing projects and efforts. For example, as the scientist indicated above, how could current capital improvement projects and proposed future projects contribute to or be adjusted to promote climate resilience? A planner believes that if such efforts

are carefully coordinated, adapting to sea level rise should not necessarily cost much more. In his words, “[with appropriate adaptation plan] Parking garage is still a parking garage. But maybe the sidewalk needs to be a little bit higher”. Even if some adaptation strategies do need additional costs, a planner argues long-term savings should be evaluated carefully to justify whether such costs are worthwhile. The answer could be yes or no, depending on the future climate and development scenarios. As a result, it is critical to keep such cost-benefit analyses up to date with the most recent scientific data, development plans, and demographic and socioeconomic trends. A planner presented a specific example: “if we were to expand Farrington, is it going to be underwater? Is it worth investing millions of dollars? Is it going to be inundated? It’s mostly the cost. We don’t want it to be a disaster for us. If we invest five trillion dollars now, is it gonna save a hundred trillion dollars in the future.” Under certain scenarios, it may be worthwhile to protect this road infrastructure in the next 100 years, but under other scenarios, the answer may be no. As a sustainability planner pointed out “analyzing the impact of variations of those scenarios” would help to better understand the cost-benefit characteristics of adaptation scenarios. There is now no definite answer for what the best alternative is. Uncertainty should be better incorporated in cost-benefit analyses for adaption techniques in future studies. The cost-benefit analysis should also examine additional built environment impacts in addition to economic costs and benefits. One planner highlighted concerns about the community’s acceptance of resilient design from the standpoints of livability and aesthetics. “Just because we need to be very resilient,” he said, “doesn't mean that we need to make very brutal and ugly that kind of infrastructure and public spaces.” When assessing transportation facility adaptation, the impacts on adjacent communities should be considered. In an example given by a scientist, we must assess whether relocating at-risk coastal roads will expose the adjacent inland low-lying community to additional threats from the ocean. “[in this example] if they move it, it exposes the whole community to the ocean. Or you actually don’t move the road, you leave the road there, and you build brand new roads someplace in Mauka. But immediately along this community is a sheer cliff…You can’t just move that road. You have a whole community attached to it. DOT has said this to the public. This is more than a road issue; this is an entire community equity issue.”

As mentioned above, community acceptance is important. The higher the acceptance from the beginning, the easier it is to implement. Community acceptance is determined by multiple factors in addition to climate resilience, such as aesthetics and livability mentioned above. It can be supported by community outreach, and the earlier in the process, the better. As a planner said, “every agency needs to do better in the initial stage to engage communities.” More importantly, more studies and efforts should be devoted to understanding the underlying community values and cultural values that are important, so that adaptation strategy could better meet the local needs and fit the local context. In a scientist's words, “What’s important to them is their cultural values and their community values that [include but] don’t just mean native Hawaiian cultural values.”

Finally, the process of monitoring the effectiveness of the adaptation strategy should be an evolving process. Several interviewees mentioned that the existing linear processing for developing adaptation strategies needs to become more cyclical in order to keep track of how policies are integrating with each other and to keep up with the evolving scientific projections. According to a coastal management expert, “I haven't been involved in this long enough to see a lot of plans get completed and implemented and monitored and evaluated, but I will say that one of the things that we're stressing is again. It needs to become a cyclical process to do the monitoring evaluation process needs to go along with the planning effort. You can’t just like to finish the plan and be done with it. It needs to be an evolving process. You are ready to visit the plan with new information.” In a transportation engineer’s words, “Plan should be updated, so plan at the beginning should have a

goal, targets and then whether you updated every year or every five years. You go back and measure the same things that you did at baseline, and you see if you met your targets or not. Are you moving in the same direction or the opposite direction of your target?" Such evolving process is especially crucial when we move practice from guidelines and recommendations to law and ordinance. Adaptation strategies, plans, and ordinances need to be evaluated iteratively and adaptively. In this process, evaluation should be carried out in accordance with up-to-date scientific information, compliance with existing requirements, community acceptance, and consistency with other more pressing goals and objectives. Coordination between agencies, sectors, and regions will be critical in developing such an evolving process.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

This study collected firsthand data through qualitative, semi-structured, in-depth interviews with relevant stakeholders in order to understand the objectives, vulnerabilities, alternatives, evaluation criteria, and challenges in the transportation adaptation planning process in response to the projected sea level rise. Through the structured decision-making framework, the study revealed the existing impacts and concerns related to transportation adaptation to sea level rise, identified adaptation planning objectives, factors influencing transportation system vulnerability, and key factors in developing and evaluating adaptation alternatives. It contributes to a better understanding of factors that influence adaptation planning to sea level rise in the transportation sector. Through the analysis, it identified the following common challenges and gaps in developing transportation adaptation plans. Based on the findings, recommendations for future studies and efforts are proposed accordingly.

First, it is not unusual that adaptation plans and options may compete with other objectives and goals. In this study, interviewees provided several examples of the potential conflict between adaptation alternatives and other needs and objectives. For example, the protection of infrastructures and properties using seawalls may conflict with the preservation of public beach access. Rock riprapping in response to sea level rise and coastal erosion may increase the amount of debris on coastal roads after flooding events. Relocating at-risk coastal roads might expose the adjacent low-lying communities to more threats from the ocean. Current development needs in at-risk areas may significantly increase the costs of maintaining infrastructures in the future. Such potential conflicts need to be carefully weighed based on community needs. More efforts and studies need to be devoted to understanding community values, developing strategic goals, and identifying their priorities in order to balance the tradeoffs.

Second, the potential conflicts between competing goals and objectives are partly due to the lack of a holistic view and working in silos. One key finding of the study is that transportation adaptation is more than a transportation issue and cannot be solved only by transportation agencies. A holistic view of resilience needs to be developed in collaboration with other stakeholders, such as land use development, utility management, environmental conservation, and so on. Collaboration between sectors would help to develop strategic plans that lower future risks while remaining consistent with other planning objectives. Coordination between transportation and utility providers, for example, could aid in the consistent planning of adaptation strategies, ensuring that, for example, raising road elevation does not create bridge clearance problems, reduce pedestrian accessibility, or increase underground utility risks. Working with communities, land use planners, transit agencies, and environmental agencies, alternative adaptation options could be evaluated for their compatibility with other sustainability goals, such as walkability, transit ridership, environmental concerns, and livability. A leading agency with authority to provide guidelines and directives could play a critical role in breaking down silos and facilitating cross-agency collaborations.

Third, uncertainty must be better incorporated into adaptation planning, and information mismatches must be resolved through stakeholder collaboration. Given the constant evolution of scientific information and future scenarios, uncertainty in future climate predictions and future socioeconomic scenarios (e.g., development, greenhouse gas emission, demographic trend, migration trend, and economic conditions) must be better incorporated into the adaptation planning process through regular updates. Stakeholder collaboration is needed to improve the coordination of spatial and temporal information mismatches in decision-making. There are, for example, mismatches between scientific prediction timeframes (typically in centuries) and planning timeframes (usually a few years to decades), mismatches between different infrastructure planning and maintenance timeframes, and mismatches between large-scale climate prediction data and smaller-scale project-level decision-making. When possible, such information mismatch should be

coordinated. If not, knowledge gaps must be recognized in the adaptation planning process, and the associated uncertainties and various scenarios should be studied and assessed.

Finally, action inertia needs to be overcome to transfer plans into actions. Several barriers to implementation were identified, including lack of funding, resources, expertise, and capacities and action inertia caused by mismatched information, outdated information, and social inertia. To overcome these barriers, garner support, and consolidate resources and capacities for implementation; community outreach and stakeholder engagement must be carried out from the initial stage. To keep everyone on the same page, a uniform framework for operationalizing the vulnerability and resilience concepts should be proposed through discussions. A clear definition of critical infrastructure, targeting scenarios, and criticality should be established to ensure consistency in implementation at different levels and across different sectors. Lastly, an iterative, cyclical planning approach with quantifiable objectives should be developed to monitor and adjust the adaptation plans periodically.

The identified objectives, vulnerability, decision-making factors, plan evaluation criteria, and implementation challenges help to better understand the key factors influencing transportation adaptation planning to sea level rise. It helps to better understand stakeholders' perceived challenges, objectives, value preferences, and priorities, as well as potential conflicts and tradeoffs in the transportation adaptation decision-making process. The findings are not only applicable to transportation systems in Hawaii, but also applicable to other coastal regions with similar climate challenges. The findings lay the groundwork for future research into more comprehensive modeling and evaluation of adaption options. The proposed recommendation could also help other infrastructure sectors to improve their adaptation planning process.

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APPENDIX A Stakeholder Interview Questions

Interview questions for planning agencies

1. Could you briefly explain the primary role and responsibility of your organization?
    a. In particular, how Sea Level-Rise (SLR) and coastal flooding hazards are related to your organization's responsibility?
2. Does your organization make plans regrading to the sea-level rise and coastal flooding hazards?
    a. [if the interviewee says no plan exists yet]
        - [Will you plan for Sea-Level Rise hazards?]
            - [if "yes" in the previous question] What contents will be included in these plans?
                - With the limited time and resources, what are the priorities on planning for the SLR hazards?
            - [if "no" in the previous question] from your perspective, what organization would make these plans?
                - What contents should be included in these plans?
    b. [if the interviewee says there is a plan]
        - Would you please briefly describe the plan(s)?
        - What are the primary concerns to plan for the SLR and coastal flooding hazards?
        - Would you please briefly describe how do you make these SLR and coastal flooding hazards plans?
            - During the planning processes, if people within your organization have different perspectives, how to move forward?
            - During the planning processes, if people from various organizations (e.g. other communities, state, local government, nonprofit groups) have different perspectives, how to move forward?
        - In planning for SLR and coastal flooding hazards, what scenarios, maps, and/or data does your agency utilized?
            - Why do you select and use these scenarios, maps, and collected data?
            - Any further analysis you think would benefit the development and implementation of the future plan(s)?
        - Are there any difficulties in implementing these plans?
        - How do you measure/evaluate the success of the plan?
3. Are there any questions that you think we should ask but we did not?
4. Would you please recommend the next interviewees for us, who you think will help this research?

Interview questions for community member and organizations

1. Could you briefly explain the primary role and responsibility of your neighborhood board?
    a. In particular, how Sea Level-Rise (SLR) and coastal flooding hazards are related to your board's responsibility?
2. Regarding to the Sea-Level Rise and coastal flooding hazards, what are your major concerns?
    a. Any concerns regarding the access to particular places/facilities/resources?
3. Are there any plans to respond to the SLR and coastal flooding hazards?
    a. [if the interviewee says no plan exists yet]
        - [Will you plan for Sea-Level Rise and coastal flooding hazards?]
            - [if "yes" in the previous question] What contents will be included in these plans?
                - Why do you think these contents should be included in these plans?
            - [if "no" in the previous question] from your perspective, what contents should be included in these plans?
                - Why do you think these contents should be included in these plans?
    b. [if the interviewee says there is a plan]
        - Would you please briefly describe the plan(s)?
            - What governmental organizations make these plans?
        - Would you please briefly describe how do you implement these SLR and coastal flooding hazards plans?
            - If you do not agree with those policies and plans made from the government, is there any method to modify these plans?
            - If people have different perspectives towards the plan implementation (how to execute the plans), how to move forward?
        - Are there any difficulties in implementing these plans?
        - How do you measure/evaluate the success of the plan?
4. Did the government discuss with citizens on the strategies to respond to SLR and coastal flooding hazards?
    a. [If the interviewee says no]
        - Is there anything you think can be improved?
    b. [If the interviewee says yes]
        - How did the government discuss these strategies with you?
        - If there was a meeting, who were invited to join these meetings?
        - If people of different backgrounds do not agree to each other, how to move forward?
5. Are there any questions that you think we should ask but we did not?
6. Would you please recommend the next interviewees for us, who you think will help this research?