INVESTMENT IN RESILIENCE FOR INFRASTRUCTURES AND CONTINUITY OF CRITICAL FUNCTIONS

INVESTIMENTO EM RESILIÊNCIA PARA INFRAESTRUTURAS E CONTINUIDADE DAS FUNÇÕES CRÍTICAS

INVERSIÓN EN RESILIENCIA PARA INFRAESTRUCTURAS Y CONTINUIDAD DE FUNCIONES CRÍTICAS

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ABSTRACT

This article discusses the process for developing business for infrastructure resilience and continuity of critical functions, using a literature review and practical knowledge from resilience experts and case studies for this discussion. The model presents risk analysis, resource identification, interoperability techniques, and the pros and cons of merging knowledge with AI. Resilience can currently be defined as the ability to prepare, plan, absorb, recover, and adapt infrastructures more successfully to adverse events. Several models of system resilience have been identified, but a consolidated process for investing in resilience has been found. Resilience projects involve several hierarchical levels of government, the private sector, and NGOs. Business for resilience results from scalable processes aimed at intermediate and long-term planning by merging multidisciplinary intelligence and AI assistance.

Keywords: Business case; resilience; data driven decisions; transportation infrastructure; AI.

RESUMO

Este artigo discute o processo para desenvolver negócios para a resiliência em infraestrutura e continuidade do funcionamento das funções críticas, usando para esta discussão a revisão da literatura e o conhecimento prático dos especialistas em resiliência e estudo de casos. O modelo apresenta a análise de risco, a identificação de recursos, as técnicas de interoperabilidade e os prós e contras da fusão do conhecimento com IA. Atualmente a resiliência pode ser definida como a capacidade de preparar, planejar, absorver, recuperar e adaptar com mais sucesso as infraestruturas a eventos adversos. Identificados vários modelos de resiliência dos sistemas, verificou-se a ausência de um processo consolidado de investimento em resiliência. Os projetos de resiliência envolvem vários níveis hierárquico do poder público com o setor privado e ONGs. Os negócios para resiliência resultam de processos escaláveis visando o planejamento intermediário e a longo prazo pela fusão da inteligência multidisciplinar e auxílio de IA.

Palavras-chave: Caso de negócios; Resiliência; Decisões baseadas em dados; Infraestrutura de transporte; IA.

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RESUMEN

Este artículo analiza el proceso de desarrollo de negocios para la resiliencia en infraestructura y la continuidad de la operación de funciones críticas, utilizando para esta discusión la revisión de la literatura y el conocimiento práctico de expertos en resiliencia y estudios de casos. El modelo presenta análisis de riesgos, identificación de recursos, técnicas de interoperabilidad y los pros y los contras de fusionar conocimientos con IA. Actualmente, la resiliencia se puede definir como la capacidad de preparar, planificar, absorber, recuperar y adaptar con mayor éxito las infraestructuras ante eventos adversos. Identificados varios modelos de resiliencia de los sistemas, se verificó la ausencia de un proceso consolidado de inversión en resiliencia. Los proyectos de resiliencia involucran varios niveles jerárquicos, desde autoridades públicas hasta el sector privado y ONG. Las empresas para la resiliencia son el resultado de procesos escalables destinados a la planificación a mediano y largo plazo mediante la fusión de inteligencia multidisciplinaria y asistencia de IA.

Palabras clave: Caso de negocio; Resiliencia; Decisiones basadas en datos, Infraestructura de transporte; IA.

1 INTRODUCTION

The evolution of the discussion of systems resilience from science into practice implementation that enables a systematic, repeatable, interoperable, flexible approach for attractive, potential, and feasible investments is discussed. How to invest in resilient solutions has been a challenge that has yet to be solved. Lessons learned and examples of successful approaches illustrate how such task was accomplished taking advantage of- and influencing policies, including observed inclusion of Artificial Intelligence (AI) alike technologies and insights. A three-stage process for “making the case for resilience in a box” is presented. Mainstreaming resilience in five diverse models and a general approach to the cost of failure helps to show how such process can be used by all looking to present resilience investment proposals for infrastructure owners or managers, elected officials, stakeholders, and the community.

2 THE PERCIVED COST OF RESILIENCE AND ITS EFFECTIVENESS

Different aspects of systems resilience have been published setting the stage for implementation; however, a clear business case for resilience is lacking. Resilience in the Department of Transportation (DOT) leadership sense requires on-going effort and represents more a way of thinking than the application of a specific tool or technique. Figure 1 is a visual representation of this reality showing the many factors, markets, functions, actors and dimensions such resilience dynamics, integration, and interoperations must be considered in.

Figure 1- Resilience in a Box

Source: the authors (2022).

Resilience, like security, in transportation can be difficult to define and can mean many things to many people. In general, resilience may be defined as the ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events. A business case approach is necessary to support resilience solutions and should include visualization tools to help evaluate, identify, and communicate the needs, vision, and benefits. Most State Departments of Transportation (SDOTs) have some level of understanding, and likely already have some initiatives in place for resilience and security of infrastructure. This effort is helped and challenged by the data created and growing using detection systems from several different sensing systems, systems key performance indicators e controls, which may exist in siloes, in integration or interoperation systems (TIBCO, 2024. CONTRIBUTOR; Kumar, 2024. U.S. DOT ITS JOINT PROGRAM OFFICE, 2020). The risk and resilience data driven decisions, therefore, need to use technologies such machine learning and AI to help identify key data types and analysis in a knowledge fusion and analytical process (Mitchell; Harris, 2012). The business case and communication for this purpose, however, must consider many federal level requirements such as the United States':

a) 2022 Bipartisan Infrastructure Law
b) 2015 Fixing America's Surface Transportation Act (FAST Act), the
c) National Highway Performance Program (NHPP), and the
d) 2012 Moving Ahead for Progress in the 21st Century Act (MAP 21) and related policies.

Mainstreaming a comprehensive resilience approach requires partnership with local and regional organizations to identify system bottlenecks that will impact infrastructure and critical government function alike. The resources required to recover from disruptions in these two arenas can quickly outstrip the capacities of any

single agency or even level of government. The resilience-in-a-box product presented here is an enhance result of an initial collaboration between the Systems and Technology Resilience Solutions (STRS), UniCuritiba, and Metro Analytics. It represents a way of thinking as much as a set of developed tools to support SDOTs and other transportation agencies as they evolve their resilience and security systems in the form of a compelling business case in a high end fast technological evolving space.

The research methodology used to support this work included both the literature review and experts' practice who must produce resilient outcomes to infrastructure, the built environment and human processes for both the government and the public taking advantage of such technologies.

3 THE PROCESS

The process of developing businesses for resilient solutions has three stages:

Stage 1 – Definition of Resilience and Identification of Measures: As stated above, resilience means many things to many people. The first step includes an analysis of the SDOT to define resilience and design goals and objectives.

Stage 2 – Risk Analysis and Program Development: Risk analysis for an SDOT is a particular challenge as most SDOTs are self-insured and unfamiliar with thinking of risk tolerance through the lens of resilience. This is an area of significant research need. Once the risk threshold is established, however, the resilience program is developed with the analysis and design from the previous stage bracketed by the risk analysis of this stage. The use of AI for risk analysis is an evolving adoption process.

Stage 3 – Mainstreaming the Resilience Program: The analysis, design, and development of a program does not guarantee its implementation. Mainstreaming a resilience program includes the marketing of the program to key internal and external stakeholders, creation of intergovernmental and public/private partnerships, and integration of the program into existing policy frameworks.

3.1 First Stage: Resilience Analysis and Design

The effort begins with an analysis of the Strengths, Weaknesses, Opportunities, and Threats (SWOT) attributes for the SDOT's resilience and security efforts. This information is organized into:

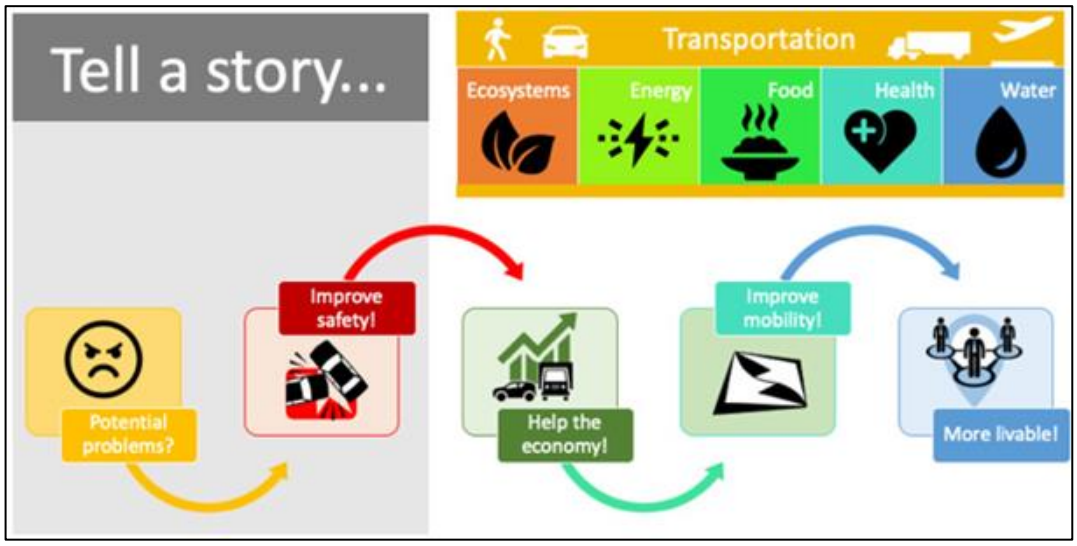
Performance Strategies: Which includes strategies to benchmark communication success and identify needs based on those benchmark characteristics. AI and other analytical tools can help provide insights for this.

Partnership Strategies: Which includes both inter-agency and intra-agency strategies.

Business Case: Which describes the risk tolerance of the SDOT in terms of the costs of disruptions against the costs of preparation, which AI and other analytical tools can help demonstrate, and

Communication Plans: That identify how the business case is effectively communicated, the purpose of the communication plan(s) is to tell the story that compels the commitment of appropriate resources to the resilience/security effort. An example of this is depicted graphically in Figure 2, which can also benefit from using AI tools like ChatGPT (OPEN AI, 2015).

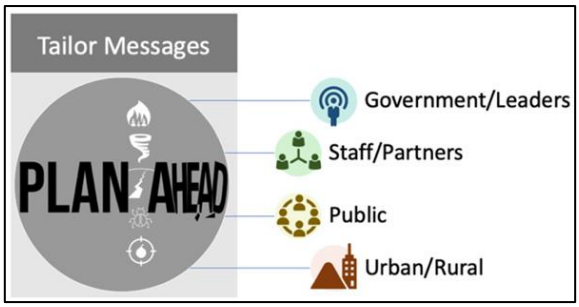
Figure 2 - Telling the Story for Resilience Investments



Source: the authors (2022).

The communication plan is customized for the stakeholders involved in the given effort. Each communication plan carries a tailored message with technical detail and language for the stakeholders involved considering the political realities of the place and time, the characteristics of the internal partners, the general public, and the geography (urban vs. rural) as illustrated in Figure 3.

Figure 3 - Resilience Business Case Communication



Source: the authors (2022).

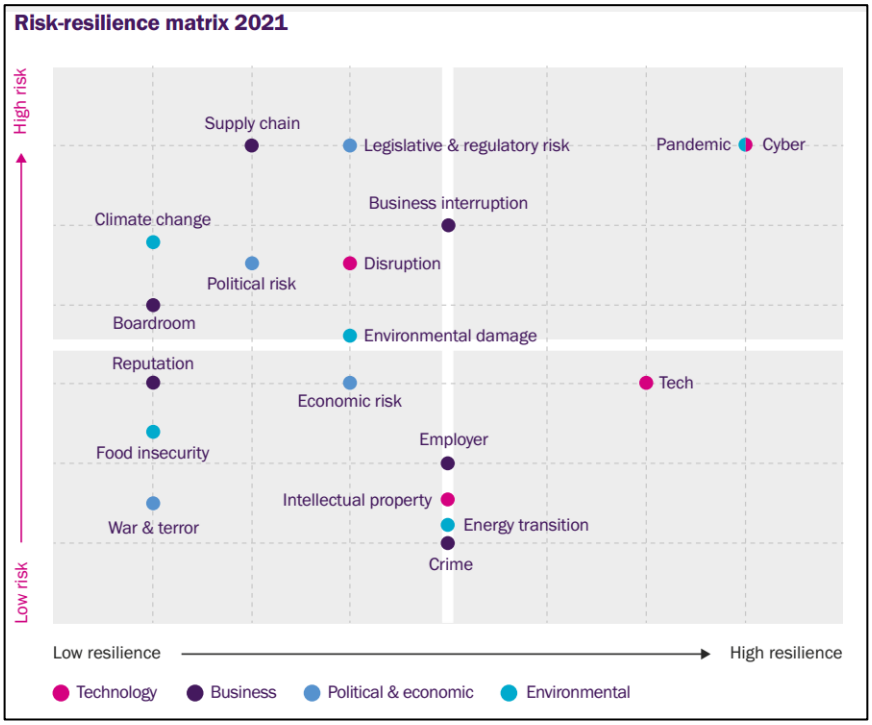
3.2 Second Stage: Risk Analysis and Program Development

At its core, the purpose of this process is to facilitate conversations that are designed to shape the products that have the highest value for the SDOT. The business case features the highest-value products through the framing of the following discussion questions:

a) Where are the critical infrastructure elements?
b) Where are the areas with zero redundancy?
c) Where are the triage plans for reconstruction of critical infrastructure?
d) Where are the locations for staging of rescue and recovery?
e) How are they served?
f) Where are the plans for calling upon multiple agencies for support?

The concept of risk analysis is not new. SDOTs have long been familiar with risk analysis in the legal arena, the safety arena, and others. The concept of risk analysis in resilience is, however, unfamiliar territory. The insurance industry has long made a practice of risk analysis and examples such as the Beazley Risk-Resilience Matrix 2021 (as depicted in Figure 4) that provides a framework for post-pandemic risk analysis in the insurance industry.

Figure 4 - Risk-resilience matrix 2021



Source: adopted from Beazley (2021, 2023).

As discussed above, however, most SDOTs are self-insured, and a defensible and reliable process by which an SDOT may properly assess their risk tolerance is a significant research need and expanded practice. This is a vital step in the development of an SDOT resilience program, and as the Delaware case study below describes, it can be a source of considerable debate. The adoption of AI for risk analysis for resilience goals is something not easily found in publicly available literature that could aid SDOT in this need.

3.3 Building the Business Case

Business Case Defined – A business case describes *what* is a recommended course of action and then describes *why* it should be undertaken. The target audience for a business case is an *external* group of key stakeholders or decision makers. A business case will present the reasons for the recommended course of action in terms of:

1. Return on Investment (ROI)
2. Future Value (FV)
3. Net Present Value (NPV)
4. Present Value (PV)

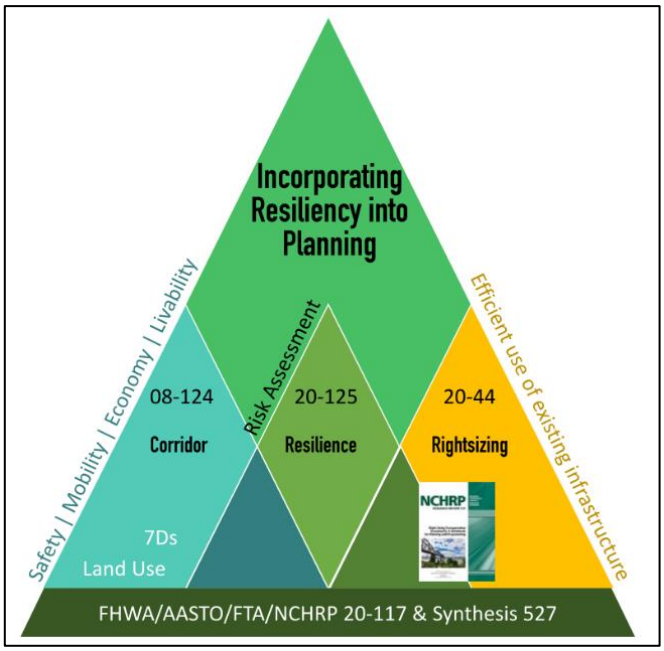
5. Payback Period, Internal Rate of Return (IRR)
6. Sensitivity Analysis
7. Benefit/Cost Analysis (B/C)
8. Comparative Analysis

The business case is written by subject matter experts (not marketing experts) to convince a target audience (probably a non-technical group but may be mixed) of decision makers to adopt a resilience mindset. A business case provides support for undertaking and a rationale for the recommended solution. The adoption of AI to enable a faster analysis of all these eight different types of actions is desirable, and well organized, enables replication and amplification of options and bottlenecks not easily identified.

Contrasted from a Business Plan – While a business case is *externally* directed and focuses on what and why, a business plan, in this case, is *internally* directed and focuses on where, when, and how. The two may have common elements but are not interchangeable. The business case must incorporate careful target audience analysis to understand the motives and priorities of the external audience so that targeted messages can be developed and delivered through vectors the external audience finds credible.

Primary Obstacles to Application – Figure 5 graphically represents one of the major obstacles to the mainstreaming of resilience. The concept is just too big and overwhelming, and an already overstretched SDOT doesn't even know where to begin. Explaining how targeted integration of resilience into planning can support other political priorities such as critical corridor management and right-sizing of transportation investments is a challenge example. It is better to consider resilience interoperability for different use contexts applicable to land use management (e.g., 08-124 of Figure 5), taking advantage of risk assessment processes (e.g., 20-125 of Figure 5), adjusted quantification (e.g., 20-44 of Figure 5), in addition to applications for security, mobility, economy, habitability, efficient use of infrastructure, among other aspects of planning.

Figure 5 - Incorporating Resiliency into Planning



Source: the authors (2022).

Other barriers to adoption and investment in resilience include political or institutional inertia and apathy. These may take the form of discourses such as:

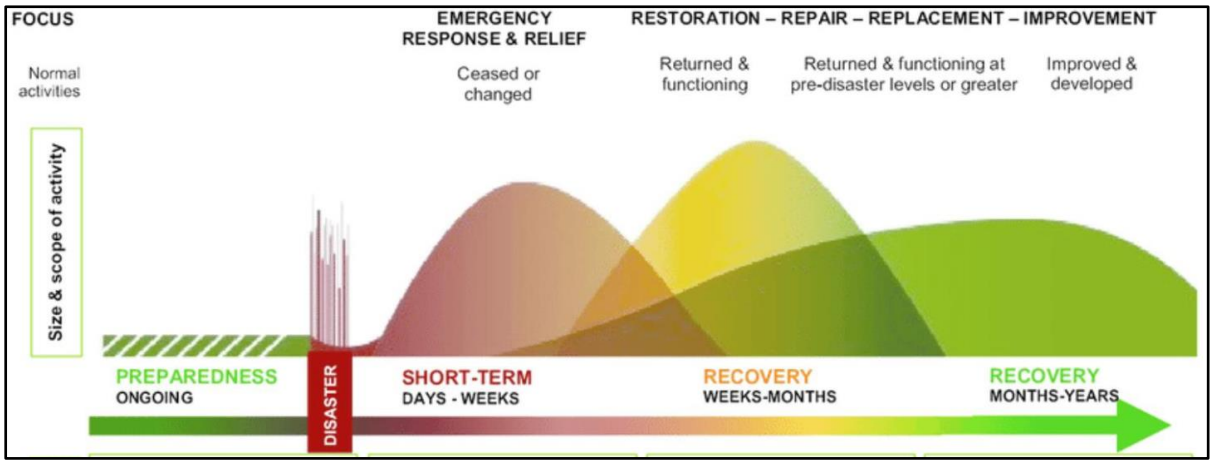
a) We're not a coastal state, and resilience only applies to things like hurricane evacuation.

b) It's fiscally irresponsible to plan for the 500-year event. We don't have the resources for that.

c) We don't have the money to maintain the roads we have, and you want us to build more?

Figure 6 below is a depiction of the FEMA resilience cycle (U.S.DHS, 2016, p. 5). At first glance it is easy to assume that we're talking about natural disasters, and that frames the entire resilience discussion. The business case broadens the discussion to include agile and adaptive responses to economic, public health, and political (social) unrest disasters (continuity of function). Resilience represents an *investment*. The responsibility for the costs of resiliency undertakings will be borne by the current decision-makers while the benefits will likely be realized by their successors. The question of "what's in it for me?" is a key component of the business case. The urgency for results that are perceived to support continuity or return to office of political positions and elected officials challenges resilience adoption timing. Full and true resilience depend on altruistic options compared to immediate and short-term outcomes that may be the expression of some level of resilience possible to be verified through the level of effort and comprehensive investment. Adverse feedback loop and decreased benefit and timing outcomes from resilience investments are another way to assess the obstacles to the potential resilience strategies.

Figure 6 - FEMA Resilience Cycle



Source: adopted from U.S.DHS (2016).

3.4 Third Stage: Mainstreaming the Resilience Program

The Five Case Model – Key stakeholder and decision groups that are the intended audiences of a given resilience business case will represent a variety of perspectives. To account for distinct points of view, each business case will need to address five distinct elements:

a) The Strategic Case: That demonstrates how the recommended course of action aligns with the strategic and management objectives of the target audience.

b) The Economic Case: That demonstrates the effectiveness of the recommended course of action in terms of future value, net-present value, and benefit/cost as described above.

c) The Commercial Case: That demonstrates how the productions and attractions, and the linkages of compatible activities are available and resilient to support the target audience's objectives in adopting the recommended course of action. It may be necessary to describe the level of effort necessary to make the commercial linkages available and resilient.

d) The Financial Case: This is related to the economic case and the commercial case in that it describes what the recommended course of action will cost to achieve in terms of ROI and IRR, as described above.

e) The Management Case: That demonstrates how the recommended course of action will be integrated into existing statutory, regulatory, or policy frameworks. This assures the target audience that they do have the capacity to adopt the recommended course of action.

The target audience for the business case will probably lack a detailed knowledge of the subject matter. It is important to avoid jargon and keep the language as simple as possible. Use short sentences and break up the text with plenty of sub-headings. Paragraphs should be no more than four to five lines long and there should be a line between paragraphs. Shorter is better than longer, though it is important to try to instill a sense of urgency in the adoption of the recommended course of action because some resilience strategies may be time sensitive.

4 THE COSTS OF FAILURE

It is difficult to argue against resilience and security in concept. One of the principal threats to such efforts, however, is the "going in" cost of such efforts. To make the business case for resilience and security, the risk tolerance of the client must be quantified. Then, the costs of failure can be measured against the going-in costs of the proposed actions. It is important to note that not all costs can be quantified in dollars. Loss of credibility and introduction (or reinforcement) of negative image of the SDOT on the part of elected/appointed officials or the public is a very real, if unquantifiable, cost.

4.1 The Cost of Failure – Resilience of Infrastructure

One of the most dramatic examples of the costs of lack of infrastructure resilience/security is observed in the aftermath of Hurricane Katrina and the levee failures upon New Orleans. It was discovered, after the fact of course, that the infrastructure of the city (transportation, water, wastewater, power) could be radically disrupted. This left thousands of people stranded for an extended time. The damage to infrastructure can be quantified, the impacts to well-being and public image is qualitative rather than quantitative, but still significant. Similar examples include Brumadinho and Rio Grande do Sul flooding and infrastructure failure responsible for extensive land and property damage and destruction, and the many lives lost (Sax, 2024; IFRC, 2024; Buschschlüter, 2024).

4.2 The Cost of Failure – Continuity of Function

The economic lockdowns caused by the COVID-19 pandemic in 2020 forced many SDOTs into unfamiliar territory. Preservation of critical governmental function is challenged when the Information Technology (IT) and security architecture is not in place for remote operations. Also, the lack of broadband capacity often

delayed services, sometimes for weeks. While fiscal impacts may have been limited, the damage to image is significant.

5 A CASE STUDY – THE DELAWARE DOT RESIIENCE PROGRAM (STAGE 3 – MAINSTREAMING THE RESILIENCE PROGRAM)

In July 2017 the Delaware Department of Transportation (DelDOT) adopted the Strategic Implementation Plan for Climate Change, Sustainability & Resilience for Transportation (SIP). This SIP is the DelDOT's first attempt to develop a strategic and cohesive plan to promote a more resilient and sustainable transportation system in Delaware. The roots of this initiative are traced back to Executive Order 41 (EO41) that was issued by Governor Jack Markell in 2013. EO41, Preparing Delaware for Emerging Climate Impacts and Seizing Economic Opportunities for Reducing Emissions, directs Delaware agencies to address both the causes and consequences of climate change. A committee and working groups were established to address the goals of EO41 to reduce emissions that contribute to climate change, to increase resilience to climate impacts, and to avoid/minimize flood risks due to sea level rise. The Climate Framework for Delaware (December 31, 2014), a key report issued under E041, summarizes the 150 recommended actions that were assigned to agencies across the state, including 19 that were assigned to DelDOT. These recommendations are organized into four categories:

a) Incorporate Climate Change into Asset Management.
b) Ensure Workforce Public Health and Safety.
c) Support Climate Resilience in Local Communities; and
d) Identify and Support Policy Initiatives that reduce emissions.

The SIP documented the action items and performance measures for each of the recommendations, provides a strategy for completion of the recommendations that addresses key challenges and requirements, and looks beyond the climate framework recommendations to consider the broader context of resilience and sustainability.

Risk analysis is described as a particular challenge to this effort. Innumerable conversations with various internal and external stakeholders resulted in an ad-hoc determination that one year's DelDOT budget represented the acceptable level of self-insured risk to the program. A more structured and analytical approach to the question of acceptable resilience risk to a program is a significant research need and could possibly borrow heavily from the insurance industry. The acceptable level of risk is a question of primary importance, as it guides the required investment levels during the program development stage. A proactive approach that policy developed to supporting such initiatives make law approaches proactive of reactive.

One of the most important take-aways of the DelDOT implementation effort is the scope and breadth of the implementation effort. While a resilience program may be "housed" within a particular office, full implementation is clearly an enterprise-wide undertaking that in the DelDOT application included:

a) Office of the Secretary
b) Planning
c) Maintenance & Operations (M&O)
d) Finance
e) Delaware Transit Corporation (DTC)

f) Transportation Solutions, including the Transportation Management Center (TMC)

g) Technology and Innovation

Integration of the SIP into various policy frameworks is the critical step necessary to mainstream resilience and security into the way DelDOT conducts itself. Resilience and security become a way of thinking. AI or machine learning adopted as a tool can aid the mainstreaming of resilience and security.

The insights into AI and machine learning pros related to SDOT resilience mainstreaming include uses in urban resilience such as early seismic warning systems, traffic management traffic control, air quality prediction monitoring and control, predictive smart infrastructure maintenance, urban resilience modeling, water resource optimization, driven emergency response, security and surveillance, and resource allocation optimization, intrusion detection systems in IoT networks, supply chain management and sustainability, autonomous mobility ecosystems (Samaei, 2024; Oseni et al., 2023; (ARAB ACADEMY FOR SCIENCE; TECHNOLOGY & MARITIME TRANSPORT; ALEXANDRIA, EGYPT; Elkady; Hesham Sedky, 2023). AI and machine learning challenges related to issues in transportation pursuant to Executive Order (E.O.) 14110 of October 30, 2023, entitled “Safe, Secure, and Trustworthy Development and Use of Artificial Intelligence” is research recently requested at the U.S. Federal Register (TRANSPORTATION DEPARTMENT, 2024). Some identified impacts to transportation resilience include implications for safety, access, equity and resilience in the transportation sector movement of people and goods, reshaping how individuals, communities, corporations, governments, and other users interact with the transportation network, including cost implications, and risks, including human-AI collaboration, standards and benchmarks. The NIST AI Risk Management Framework from October 2022 is identified as a recommended approach.

Finally, the SIP document also includes outreach and training to political subdivisions of the State and there is an entire section in the plan document on inclusion of local entities. There is also a section on monitoring and reporting of the performance measures identified during the program design phase. This provides DelDOT the opportunity to prove and celebrate successes and defend resource allocations. Potential resources at federal and state levels are also included.

5 CONCLUSION

This article discussed the process for developing business for infrastructure resilience and continuity of critical functions based on literature review and practice knowledge including case studies. The methodological developed model including risk analysis, resource identification, interoperability techniques, and the pros and cons of merging knowledge with AI to aid making the case to investing in resilience. It took advantage of several models of system resilience to consolidate the process for investing in resilience, considering projects that involve several hierarchical levels of government, the private sector, and NGOs, and the need for the business for resilience to be scalable, intermediate and long-term, comprehensive, multidisciplinary, and inclusive of machine learning and AI.

Resilience and security can be difficult to define and can mean many things to many people, but a clear and appealing business case for investing under the resilience concept and approach has been lacking. Resilience, like security, is very easy to discuss but very difficult to effectively implement, or invest in. The process for development of a business case for resilience in infrastructure and continuity of critical function developed has

three stages:

Stage 1 – Definition of Resilience and Identification of Measures

Stage 2 – Risk Analysis and Program Development

Stage 3 – Mainstreaming the Resilience Program, which includes the marketing of the program, creation of intergovernmental and public/private partnerships, and integration of the program into existing policy frameworks.

The costs of failure are steep and go well beyond responses to natural disasters. Resilience of infrastructure and continuity of critical function are the two primary areas that should be of concern to SDOTs. The DelDOT implementation effort demonstrates that resilience is an enterprise-wide undertaking and must become a way of thinking rather than a specific program. The careful use and adoption of machine learning and AI is a technological tool and support growing need and option that is still not well understood. The continuous effort to making the case for resilience solutions investments now supported in the U.S. by funded mandates is the confirmation of the need and a movement towards answering the needs of infrastructure owners and managers, elected officials, stakeholders, and the community.

AUTHOR CONTRIBUTION STATEMENT

The authors confirm contribution to the paper as follows: study conception and design, data collection, analysis and visualization of results, and manuscript preparation. All authors reviewed the results and approved the final version of the manuscript. This is an original paper. This paper is enhanced and updated from an earlier manuscript the authors submitted and got approved for a poster presentation at the 2022 Transportation Research Board of the National Academies of Sciences, Medicine, and Engineering.

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