Advancing the Marine Transportation System Through Automation and Autonomous Technologies:

Trends, Applications, and Challenges

U.S. Committee on the Marine Transportation System
6th Biennial Innovative Science and Technology Conference
Summary of Recommendations

December 2021

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U.S. Committee on the Marine Transportation System
1200 New Jersey Avenue, SE
Washington, DC 20590
202-366-3612
www.CMTS.gov

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Forward

This summary and recommendations do not represent the opinions of the CMTS Maritime Innovative Science and Technology Integrated Action Team (MIST IAT) or member agencies of the CMTS, but rather those of conference presenters. The MIST IAT has used and considered recommendations from previous innovative and science conferences to guide workplan initiatives.

Summary of Conference Recommendations

The U.S. Committee on the Marine Transportation System (CMTS) in partnership with the Transportation Research Board (TRB) held the Sixth Biennial Marine Innovative Science and Technology Conference, "Advancing the Maritime Transportation System through Automation and Autonomous Technology: Trends, Applications, and Challenges," virtually on March 15-17, 2021. The conference was rescheduled from its original 2020 date to a virtual format due to the Covid-19 pandemic. Over this three-day forum, 10 general breakout sessions with over 50 experts from government, academia, and industry shared expertise on topics ranging from autonomous ships and technologies to maritime data access, port and harbor automation, digital twins, autonomous drivers and challenges, and use of point data. Over 130 representatives from academia, federal agencies, and private industries participated in the virtual event.

The conference concluded with an interactive closing summary session held on March 19, consisting of breakthrough session overviews, key takeaways, and discussion on leveraging information to inform CMTS strategy and improve overarching policy for the safety, security, and efficiency of the marine transportation system (MTS). During the summary session, conference organizers presented five general framing questions to guide discussion and formulate a summary on challenges and opportunities within maritime autonomous and automated technologies in the MTS. Recommendations within this report were gleaned from these framing questions, conference breakout sessions, plenaries and keynote speeches, and give an overview of the highlights, synopses and the major points discussed throughout the event. Also identified are specific gaps, opportunities, and needs that MTS stakeholders should consider informing future research and policy prioritization.

Autonomy and autonomous applications within the MTS hold promise for improvement of maritime safety, quality of life, supply chain efficiency, and potentially costs for goods and services. However, many challenges remain that will require research and development to evaluate, assess and test evolving technologies. There are many opportunities for implementation and application for both widespread benefits, yet diligence will be required to work through the regulatory and technological impediments for safe and effective

implementation of autonomy and autonomous technology within the MTS. General recommendations are as follows:

- Collaborative partnerships need to be developed or enhanced between federal, industry and academic stakeholders to improve data standardization, interoperability, application and access to data to support and develop autonomous technology. Partnerships can further improve cost-benefit of financial investments in foundational technologies for autonomy.

- Domestic and international regulations, standards and guidance will need to be developed to sufficiently support enabling autonomous technologies. International Maritime Organization (IMO) is working to have updated regulations by 2030. Labeling autonomous technologies as their functional equivalencies within regulations may help to serve as an initial pathway.

- Long-term, designated testing areas were recommended by participants to support development of maritime autonomous technologies in the U.S.

- Shifts in maritime skillsets will require updated workforce training and curriculums within training programs to ensure automated and autonomous technologies are safely and effectively integrated into the MTS, particularly with assisted autonomy being first for implementation. It is vital that the human element remain alongside increasing autonomous applications.

- Research (and, ideally, the funding and other resources to support) is required to better understand how best automated and autonomous technologies can be used to improve socio-economic conditions as well as safety, environmental, and other long-term social and cost benefits.

- As a result of the data intensive nature of this technology, cyber security should be a priority to enable and safeguard autonomous and semiautonomous systems and their operations.

Conference Overview

The U.S. Committee on the Marine Transportation System (CMTS) in partnership with the Transportation Research Board (TRB) held the sixth biennial marine innovative science and technology conference, "Advancing the Maritime Transportation System (MTS) through Automation and Autonomous Technology: Trends, Applications, and Challenges," virtually on March 15-17, 2021. The conference was originally scheduled to be held at the National Academy of Sciences in June 2020 but was rescheduled to a virtual format due to the Covid-19 pandemic. The event was organized to foster the development and deployment of automation and autonomous technologies within the MTS, supporting ocean exploration, supporting the MTS, and identify regulatory oversight and governance issues related to autonomy and autonomous technology in the MTS. Within this three-day forum, 10 general breakout sessions with over 50 experts from government, academia, and industry shared expertise on topics ranging from autonomous ships and technologies to maritime data access, port and harbor automation, digital twins, autonomous drivers and challenges, and use of point data. Over 130 representatives from academia, federal agencies, and private industries participated in the virtual event.

Similar to previous innovative science and technology conferences, this event concluded with an interactive closing summary, consisting of breakthrough session overviews, key takeaways, and discussion on leveraging information to inform CMTS strategy and improve overarching policy. During the summary session, conference organizers presented five framing questions to guide discussion on challenges and opportunities facing autonomous and automated technologies in the MTS. Recommendations within this report were gleaned from conference breakout sessions, plenaries, and keynote speeches in the context of the five framing questions. This report also gives an overview of the highlights, synopses and major points discussed throughout the event and identifies specific gaps, opportunities and needs MTS stakeholders should address to inform future research and policy prioritization for safe and effective implementation of autonomous technology and automation within the MTS.

Keynotes and Plenary Vision

The United State MTS is vast, encompassing waterway networks, ports and intermodal landside connections that allow the movement of people and goods by leveraging our maritime resources. Advances in automation and autonomous technology within the MTS will allow for a transportation revolution by increasing productivity, economic benefits, environmental sustainability, and welfare of communities nationwide. While there are substantial opportunities for the application and implementation of maritime autonomous technologies, it will require signification collaboration with the varied stakeholders by federal agencies to encourage and support products that enable its effective and safe application and oversite. Additionally, federal agencies can enhance internal operations and services by leveraging and implementing these technologies. Current examples include U.S. Navy maritime autonomous surface ships and National Oceanic and Atmospheric Administration (NOAA) bathymetry sail

drones to potential improvements of lock and dam function through remote control technologies by the U.S. Army Corps of Engineers (USACE).

Standards are being developed at the international level through the International Maritime Organization (IMO) and U.S. regulations should be considered that do not hinder innovation. For example, as of January 2020, U.S. Coast Guard (USCG) does not allow an electronic version of Official Logbooks for U.S. vessels, though this could provide valuable baseline data for maritime autonomy[1]. Partnerships are needed at the domestic and international levels to coordinate, develop, and deliver foundational data and products to enable autonomous technologies, promote data sharing, and support increased cyber-security. The U.S. MTS can gain further insight and lessons learned from evolving efforts in Europe and other early adopters for both vessel-based and intermodal autonomous technologies.

Keynote Address I: Commissioner Daniel B. Maffei

Commissioner Daniel Maffei (now Chairman) of the Federal Maritime Commission, touched on recent technological advances within the marine transportation system while noting historical innovations: simple in some cases, such as the shipping container, that altered and advanced MTS operations on a global scale. Three main reasons exist for implementing innovative technologies including autonomation in maritime transportation with potential benefits for the supply chain and a safer work environment. Collaboration on supportive initiatives is vital among agencies, although they must be cognizant of potential distractions that new technologies may cause. The three main purposes for implementation of automation are as follows:

1. *Increase productivity of the marine transportation system, leading to economic benefits.* Automation can be used to address issues related to import/export imbalances, support more fuel-efficient cargo ships to move more cargo at less cost – though for seamless transition, improvements must also be made at shore-side facilities for efficiency.

2. *Improve service and reliability to ultimately benefit customers.* Utilizing technology to improve tracking of containers/cargo, along with the predictability of shipments by customers is key. Integration and availability of data is paramount to successful collaboration across stakeholders.

3. *Improve sustainability and welfare of people.* For the planet and people, automation has many opportunities. Machine learning and artificial intelligence could increase safety by taking humans out of harm's way by eliminating monotonous and dangerous tasks for mariners and port workers.

[1] https://www.dco.uscg.mil/Portals/9/OCSNCOE/Drill-Downs/DD014-Vessel-Logbooks.pdf

Obstacles facing implementation of autonomous technology in the MTS include a constantly operating work environment, public opinion, and opposition, as well as restrictive laws and policies that could hamper innovation and technological adaptation.

Keynote Address II: Focus on Automation and Autonomy in Marine Transportation: RADM James Watson.

RADM James Watson, President and Chief Operating Officer of the America's Division of American Bureau of Shipping (ABS), provided insight on how ABS is addressing regulatory challenges with autonomous development in the maritime industry. Automation and autonomous terminology and operational decisions were described alongside differences between the two, with fully autonomous systems having no human interaction and semi-autonomous technology having human interaction. Autonomous functions have already been implemented in various ports and for ships (particularly navigational), though many challenges exist – particularly regarding regulations. The ABS anticipates international regulations will be adjusted to safely introduce these technologies to industry, though implementation also depends on comfort levels in society, the marine ecosystem, human errors and marine insurance, as well as the marine operations chain. Maritime innovations are tied to adaptation of technologies and the level of comfort throughout the supply chain (port/waterways/high seas ship co-ops). The IMO has conducted a regulatory scoping exercise to address shortcomings of current policies for maritime autonomous surface ships (MASS): including terminology, classification, interpretations, and responsibilities. ABS is using a goal-based, stepwise process involving collaborative efforts to introduce autonomous and semi-autonomous vessels into improving and adapting regulations.

Currently, ABS operates in "stovepipes", looking at different components of a system, though with MASS technology, regulations need to address these issues as a whole – through utilizing testing areas. ABS is working to address and refine foundational requirements including cyber, software, and data using a novel concept approach with a new technology qualification for risk assessments and system engineering verification. ABS regulations and qualifications are adapting to MASS technology to keep operating systems safe and ensure higher reliability of equipment. ABS does this to ensure safe implementation of autonomous functions, that humans stay in the loop, use of structured and engineered verification and validation processes, stakeholder collaboration, and continued monitoring of progress at IMO.

Several take-aways were noted: There was a recommendation for testing areas in the U.S. for autonomous applications to lead in autonomous technology development. Training on underlying technology in maritime academies and training centers (such as cyber security) needs to keep up and stakeholder cooperation is key. The technology is coming.

Keynote Address III: Focus on European Inland Waterways: Dr. Edwin Verberght

Dr. Edwin Verberght, University of Antwerp, highlighted the concept of innovation implementation in a broad context, concluding that the social benefit must be high enough for acceptance and broad application. Innovation perspectives vary depending on an individual's

role but is generally held as a pattern of failure and successes through a multilateral network involving research, government oversight, suppliers, and consumers - with the end goal of benefiting society. Current maritime innovations in Europe include alternative fuels, digital advances with sensors and automation regarding vessel operations. Electronic navigational tracking and electronic charts contribute to safety of inland waterway transport, and automated mooring is even being considered. “Greening” is considered, though costs are currently too high for this to be a viable option. Furthermore, an analysis of liquid natural gas (LNG)/Diesel dual fueled engines shows that while particulate emissions are reduced, greenhouse gas (GHG) emissions are not.

Challenges hindering innovation are varied, ranging from coordination and collaboration of stakeholders to policy bottlenecks. Policies must align with various stakeholders for innovation to be successfully implemented.

A cost benefit analysis was discussed of automated vessels, with conclusion that innovation saves time, costs and can reduce emissions. Costs include investments in data security, improved and updated infrastructure, and training of workforce. Net results will depend on the crew size being displaced.

In policy roles moving forward, there have been many challenges in Europe: stakeholders are complex and fragmented. Regulatory bottlenecks exist, particularly regarding alternative fuels and LNG, and will need to be removed and updated as to not hinder innovation in automation. Regulatory agencies and governments can either invest in underlying technologies and improve policies in a supportive role or sit back and let the market determine innovations on its own.

Plenary I: Maritime Public Agency Stewardship Perspectives

In this plenary, representatives from USCG, NOAA, USACE, Office of Naval Research (ONR), and the Department of Transportation’s Highly Automated Systems Safety Center of Excellence (DOT HASS-COE), shared perspectives on agency roles related to marine transportation system (MTS) automation and autonomous technologies. USCG is focused on reducing aggregate public risks associated with autonomy through standards setting and compliance verification. NOAA is developing and utilizing automation and autonomous technology through collaboration with non-government organizations (NGOs) to improve navigational services and data collection. ONR is developing and utilizing autonomous technology to maintain resilience and effectiveness in a rapidly evolving national security environment. The DOT is establishing a new office - the Highly Automated Systems Safety Center of Excellence - to integrate automated technology safely and effectively through multimodal systems and partnerships. USACE is focused on creating a more resilient inland waterways system through public and private partnerships. Several take-always emerged from the panel that are applicable to the separate missions of each agency.

When transportation system innovations advance, the impacts on humanity can be substantial from the industrial revolution to air travel. These advances can happen quickly, thus it is vital

for agencies to coordinate and collaborate through multi-modal and international partnerships to ensure safety, mobility, and inclusiveness for all users. Panelists mentioned several different concerns and potential bottlenecks: regulations and policies, cyber security, and designating virtual and real-world training environments. Agencies must be cognizant of disrupted skillsets and be able to adapt through updated trainings and career transition programs. Perhaps most notable – panelists agreed on the importance to keep people in the loop, and to prepare for high technology failures with low technological solutions.

Plenary II: Automation and Autonomy: Northern European Perspectives and Lessons Learned

Insights from Northern European maritime industry and government were shared in this plenary. Panelists included representatives from Holland & Knight, LLP, One Sea Ecosystem, Massterly AS, GL – Maritime, and the Royal Norwegian Embassy. Panelists stressed that legal frameworks should not impede innovation, yet currently the regulatory and legal climate is holding back autonomous technology applications in the commercial sector. IMO regulations are being improved with final guidelines expected out by 2030, yet technology is currently outpacing regulations. Over the long-term, automation technology implemented shipside must be complemented by shoreside equivalencies; to do this, the US must import a culture of innovation and focus on standardizing data collection and collaboration in the interim.

In Northern Europe, there is a partnership of multiple companies working on various aspects of maritime autonomy brought together under the umbrella of the One Sea Autonomous Maritime Ecosystem. This collaboration depends on digitalization of records and data, and pushes new innovations based on six overarching topics: technical, security, regulatory, traffic control, ethic concerns, and operations with a primary goal of leading the way towards an operating autonomous maritime ecosystem by 2025[2]. In this region, autonomous technology has seen great strides within the private sector due to cost efficiency, new revenue models, and increased safety and sustainability. Autonomous technology in ships is still relatively new. Much of this technology will make it to crewed platforms before full autonomy: autodocking, auto mooring, skill qualification and verification issues. Functionality of this technology is crucial and must be safe. Key factors for evolvement of autonomous technology must include political interest and willingness, early involvement, and cooperation in research projects by stakeholders, and a holistic encompassing approach including many aspects and factors. Technology alone isn't enough to make ships safe.

Norway is focusing on initiatives towards green maritime transport, emission reductions, workers skills and knowledge, and digitalization. There remain challenges including existing regulations, data access, training, testing facilities, cyber security, and international collaboration.

[2] https://www.oneseaecosystem.net/

Plenary III: Multimodal Sector Technology Perspectives

Panelists included researchers representing Vanderbilt University and Virginia Commonwealth University, as well as industry representatives from Virginia International terminals, LLC and Kongsberg Maritime, Inc. Several overarching perspectives were discussed within this plenary, all focused on current autonomous applications within the MTS, and ways to improve. Advancing and implementing autonomous ships will take collaboration from multiple partners – autonomous technological implementation will likely happen incrementally. Thoughtful use of early data collection and semi-automation streamlining reservations from truck company dispatchers at ports can lead to vast improvements for cargo transfer and alleviate congestion problems portside. Improved data collection shoreside can aid, model simulations and analytics to help us better understand potential risks associated with autonomous vessel interactions between crewed and uncrewed vessels or environmental conditions, though input data (such as AIS tracks) is difficult to clean, and data is lacking for incidents and accidents between these two categories.

Within inland waterways, remote control locks and bridges are currently being implemented across the world. Lock and bridge operators should consider various aspects of technology implementation that could decrease workloads, as well as training requirements, component system architecture for control and monitoring, and safety requirements. Automatic data collection should be considered to improve continuity of workflow and simplify regular maintenance, though it is crucial to maintain the human aspect of operations in the event of incidents and disruptions. Foundational functions (such as automatic data collection) that are needed for full autonomy in the future need to be integrated into our products today to inform machine learning and automated intelligence decisions in the future. Regulatory impediments should be improved as to not impede increased autonomous implementation.

Takeaways from Technical Breakout Sessions

Autonomous Ships and Technologies I, II: Two distinct breakout sessions were devoted to autonomous ships and underlying technologies; the first being focused on application, situational awareness, and approaches to autonomy in shipping and the underlying foundational technologies. The second focused on foundational technology underlying artificial intelligence, the importance of collaboration, legal frameworks, and best practices. Application of autonomous intelligence in ships could increase safety, reduce human error, optimize efficiency, and reduce costs. However, underlying sensors must all work together for this to occur, cybersecurity issues persist, and legal frameworks and regulations must be updated for autonomy to fully develop and be implemented in a meaningful way. Furthermore, implementing autonomous ships alongside crewed vessels will be challenging in waterways, particularly regarding communications.

Federal agencies should prioritize research and development focused on sensor integration, cyber security, and best approaches to legislating artificial intelligence and autonomy in maritime shipping and transportation. Furthermore, collaboration amongst agencies and

private industry will be vital to develop sound regulations and technologies and to transition workforce training to include new duties and skills. Autonomy and automation in the maritime environment could lead to better quality of life, safer ships, and social and economic benefits.

Enabling Autonomous Operations on Inland Waterways I, II: Transportation along Inland waterways is benefitting from increasing autonomous technologies aboard transiting vessels (smart shipping initiatives, travel time statistics) and MTS infrastructure (remote lock operations, river information services), with the potential for even more improvements. The future of navigation data may be more accessible, interoperative, and responsive. Weather observations derived from ship's automatic identification systems (AIS) have the potential to expand and increase the accuracy of weather forecasting, though this technology is still ongoing evaluation and optimization for satellite reception and data tracks to NOAA. However, this exciting technology has the possibility to turn thousands of ships into weather sensors to improve forecasts for all users. Travel time statistics used to predict shipping transit times and assess waterway or area closure impacts are underway and available, though opportunities for improvements for traffic monitoring and voyage planning remain. Remote lock operations under development by the U.S. Army Corps of Engineers contain multiple elements and sensors, enabling them to monitor structural health of infrastructure to improve maintenance and safety along waterways.

Challenges include staying on top of new training for workers in tandem with work force acceptance of technologies. Funding priorities focusing investments on maintaining existing infrastructure could deviate resources from integration and installation of new technologies. Coordination across sectors and stakeholders is key to integrating these technologies, though tangible benefits from implementation may be difficult to quantify.

Port and Harbor Automation: As vessel operations become more automated, automation must be implemented within shoreside operations to avoid supply chain disruptions. This breakout session noted various tradeoffs, concepts, and trends related to port and harbor automation on an international scale, while mentioning the importance of simulation and emulation in planning and designing of terminals. Speakers suggested that operations are moving towards remote control of vessels to improve safety and potentially increase the window of port operations around the clock. Panelists noted that automation will be applicable to all vessels, though size may be a constraint and new training will be required. Furthermore, automation is more applicable within container terminals than bulk terminals. Automation can be implemented at various points within a port from a vessel to landside transfer, with many opportunities for benefits.

Automation landside is currently hampered by a lack of consistency. Across the board, there is a need for local, regional, and national planning criteria and standards for safety, resiliency, and efficiency. Further challenges exist related to the data sharing side of automation and complication by different systems (sometimes proprietary) across numerous stakeholders. Large upfront costs for automation implementation can also be difficult to correctly value with

unknown life-time benefits. Most of automation benefits may result from port design, and it can be hard to retrofit into an existing operational terminal.

Maritime Data Access: This technical breakout session showcased and included discussion on research related to maritime data access. Panelists noted that discoverability of data continues to be challenging for end users. Occasionally, data sources can provide conflicting information, making it difficult to discern which source is correct. Costs associated with access to various forms of data remain a limitation to new research. Broad access and sharing of real time data is critical to support planning, management and advancement of maritime transportation infrastructure by government agencies, industry, and other stakeholders.

To foster improved decision making in maritime transportation infrastructure, research is ongoing to create a large-scale data visualization tool for maritime freight transportation. Platforms that curate data from multiple sources and present it in a user-friendly way are helping with these challenges, though there is still room for improvements. Increased collaboration and partnerships can help to streamline data accessibility for stakeholders, and creation of a shared national platform for maritime data access could ease collaboration efforts and boost innovation within the United States. Accessibility of data, particularly for navigation, is essential for safe and efficient transportation operations.

Research has proven AIS data as a valuable tool for long range freight planning. Recent research funding proposals (RFPs) suggest that there may be increased use of AIS data as training data for artificial intelligence and machine learning (AI/ML) research, but access to newer AIS data remains challenging. Improvements to the interoperability of data sets, such as geospatial data (e.g. AIS and truck-based GPS location tracks), enables the discovery of important trends such as intermodal connectivity bottlenecks to the MTS. When combined with economic impact data, these kinds of discoveries can highlight efficiencies and inefficiencies in transport hubs.

Use of Point Data to Understand MTS Operations: In this breakout session discussing research related to use of point data, speakers discussed successes in collaboration. An interagency government effort between the Department of Homeland Security (DHS) and the U.S. Army Corps of Engineers is producing a Port Resilience Assessment and Decision Guide to inform investment support, better understand functional resilience and improve other port operations decisions. Ongoing research is also addressing cyber prone disruptions through a tool to support data driven risk assessments. Another panelist spoke on the usefulness of GPS position data for multimodal transportation analysis and visualization. Marine transportation is reliant upon the underlying data supporting operations, as well as the many interdependencies of the systems hosting this data working together.

Single data sets can be used for multiple purposes. As in other sessions, it was noted that collaboration, communication, and data sharing is vital to increase efficiencies and improve upon existing technologies for economic benefit. The marine transportation system is a multi-modal, multi-layered system that continues to evolve. In stakeholder collaboration and

operations, all interests should keep a holistic viewpoint to avoid silos and look at all aspects in protecting MTS operations through disruptions - including prevention and timely response. Of note, even with advances in use of point data and increases in data use and automation, a low tech, human element will be needed to avoid potentially large disruptions when the underlying technology is compromised or imposed upon.

Automation Drivers and Challenges: This panel showcased insights into public sector concerns with marine terminal automation, the possibilities of autonomous vessels, and the marine / landside nexus. The complexity of the port and terminal environment makes it difficult to program for automated decisions (e.g. how does a self-driving truck cope with outliers or exceptions?). Further challenges were raised in a research scenario relating to negative economic impacts derived from jobs lost to increased digitization and automation of marine port terminals, with an example in British Columbia. Drivers of automation can sometimes become the challenges. Policy makers and employers must look closely at the economic, productivity and environmental benefits of automation as they are not necessarily always positive. Automation should not be implemented at the expense of social equity within the United States. Policy makers should engage local communities and labor groups regarding how best to transition, how to retrain the workforce, and how to balance the needs of nearby stakeholders near ports.

Research on maritime clusters in the United States indicated two preliminary trends: cluster members do not share the same level of information, and there is a need to further consider the impact of automation to the maritime sector. Clusters have the possibility to foster innovation, automation, data integrations and advocacy, though there are geographic and industry “alliance” hurdles related to business competition and land or water routes. Automation policy development and regulations and collaboration/partnership across various levels of government (i.e., local, state, federal, international) is essential for standards setting prior to the technology becoming obsolete or superseded.

Innovations in Data Driven Automation: The utility of data driven innovations was discussed in this session, noting the importance of data as a foundation for autonomous operations, a source of innovation in efficiency for port stakeholders, and can contribute to a useful tool for non-biased port infrastructure maintenance and improvements. Innovative foundational technologies such as Blockchain have emerged as potential drivers improving the competitive position of maritime port communities. The blockchain system is enhancing and improving data interchange between stakeholders in the Port of Veracruz supply chain to improve operational experience, lower entry barriers, reduce processing time, and to focus on common projects. Implementation challenges for other areas include data standards, funding, and trust among stakeholders and competing business. Panelists further explored the importance and challenges of updating physical logbooks into digital formats for continuous record keeping and to support autonomous technologies. Federal agencies must address and update current regulations to improve and replace physical logbooks with digital record keeping to advance human assisted

automation and data driven automation training as to not impede commercial introduction of crewed or crewless autonomous vessel operations in the United States.

Furthermore, trade off analytics (techniques to identify and structure stakeholder objectives and doable alternatives) can be a useful tool for asset management and development of domestic port planning. An asset management tool for port planning is being developed through MARAD's Office of Ports and Waterways Office targeting in-water structures as critical infrastructure vulnerable to unmanaged risks. This tool can establish risk-based management plans to defend and prioritize funding for capital-intensive assets by balancing risk and revenue growth in port planning. Input value measures within the tool can be customized by desired objectives of individual ports.

Navigation Safety: For the continuity and fluidity of operations within the U.S. MTS, navigation safety is of the utmost importance and was the focus in this break out session. NOAA discussed ongoing collaboration efforts in utilizing autonomous underwater vehicles, unmanned surface vehicles, and unmanned aerial vessels for potential near shore and rapid response situations and bathymetry missions. One presenter discussed a recently published guideline for automated / autonomous operations on ships from ClassNK, contributing to requirements on each stage of design and development, installation, and maintenance management during operation of autonomous technology. The future of automated navigation product support will rely on inter-operable data and the transition from traditional raster/paper compilation towards new modes of navigation with autonomous shipping.

Several pressing issues arose regarding navigation safety. Guidelines and regulations are needed to inform protocols and best practices moving forward, and collaboration is needed across all interested parties. Participants also mentioned the need to take note of past mistakes, both within the human interface and autonomous systems to aid in artificial intelligence learning.

Digital Twins: The use of digital twin technology in training, testing, and troubleshooting machine learning, artificial intelligence, and autonomous and automated technologies, particularly in areas lacking real world training areas. Advances in video technology and video processing has aided USACE in development of structural health monitoring for inland waterways navigation infrastructure to continuously provide inland navigation asset managers the necessary information to ensure continued operations during disruptions. However, contact sensors alone cannot comprehend the full picture, and underlying infrastructure is required.

Discussion continued the use of digital twins as an important step in structural health and risk assessment, risk mitigation, and long-term stewardship of maritime heritage structures. Digital twins are valuable in that they can be updated over time for optimization, can be enabled by "big data", and can transform data into decision making. Funding, privacy, and complexity of data and litigation are all challenges that need to be addressed. Digital twins can also be utilized to optimize life cycle costs of lock gates to initiate effective risk informed budget plans for

maintenance and repair. This could be done through creation of an integrative framework to define decision statistics, data dissemination and acquisition. Unique challenges include implementing detail into digital twins for most accurate representation and usefulness, and energy costs.

Call to Action

The final day of the conference held March 19, 2021, convened participants, speakers, and technical presenters to facilitate discussion and understanding from the conference proceedings. Moderators from each breakout session presented on main take away points from each session, summarized above. In addition, conference organizers presented five framing questions to formulate a summary on challenges and opportunities within maritime autonomous and automated technologies and a call to action for future work:

- What does automation and autonomy on the MTS look like in the future (5-10 years)? How will it reshape the way we move goods and people via the MTS?
- What are the key challenges and disruptive influences inhibiting automation and autonomy now, and in the future?
- What promising new or emerging technologies/methodologies do you see as most beneficial?
- What are the highest priority R&D gaps or needs that federal agencies charged with stewardship of the system should be paying attention to?
- What are the opportunities now, and in the future to advance these technologies, and co-produce solutions through public and private sector partnership?

MTS in the future

For these technologies to advance, MTS stakeholders must improve the underlying technologies behind automated and autonomous MTS innovations. One moderator suggested that remote controlled, unmanned vessels will be common by 2025, providing advanced support systems and assisting with cognitive processes of human operators (Autonomous Ships and Technologies I). Remote-controlled ocean-going vessels will be more common by 2030, and fully autonomous unmanned ocean-going vessels by 2035. Within our inland waterways, speakers suggest a more accessible, interoperable, and responsive system leading to improved remote lock operations from increased sensor array deployment, more stable communications network, and increased cultural acceptance of technology (autonomous operations on inland waterways). Increased on and off-dock autonomy and assistance is to be expected alongside improvement of automated truck gate operations within ports (port and harbor automation). Another session suggested an increased use of digital twins and supply chain digitalization as providing better and more efficient data interoperability.

Future Outlook:

- Increased interaction between autonomous vessels, crewed vessels, and everything in between

- Highly autonomous port terminal in Vancouver (within 10 years)
- Autonomous technologies unfolding incrementally over time
- Increased applications for autodocking, auto-mooring, and other high risk or monotonous tasks alongside a decrease in human error and potential costs
- Mix of small semi and full autonomous ships, moving towards full autonomy (10 years)
- More and in-depth learning of artificial intelligence and data learning
- Some sectors will see widespread autonomy in smaller, focused applications such as data collection (drones, bathymetry, etc.)
- The future of maritime data access looks like multiple partners providing data through a shared national platform.
- Increased focus and improvements on cyber security, regulatory improvements, testing facilities, and international collaboration

Challenges and Disruptive Influences

Challenges exist for improvement of maritime automated and autonomous technology, as well as the underlying technologies, innovations, and testing required to improve performance and successful integration into the MTS. There are major cybersecurity risks associated with fully and semi-autonomous vessels that must be addressed for safety and security of operations. Legal frameworks, regulations and international maritime law was not written with autonomy in mind and must be amended to achieve full autonomy. Work force availability and even societal acceptance of widespread autonomous technologies could be problematic for implementation. Multiple moderators stressed the importance for interagency, industry and international collaboration on underlying technologies supporting autonomy and autonomous functions, as well as underlying data. Data interoperability is currently complicated by different protocols, system applications and numerous interested stakeholders. Furthermore, upfront costs of autonomous technology can be difficult to fund or fully value cost benefits. One speaker pointed out that infrastructure silos are creating gaps, and that group exercises are a good way to identify and overcome these gaps. Financial hurdles also remain regarding investment.

One moderator noted that drivers of automation can sometimes become the challenges, agencies must closely analyze the economic, productivity and environmental impacts of automation, as they may not always be positive. Automation should not be at the expense of social equity. Local communities and labor groups should be engaged regarding how best to transition, how to retrain the workforce, and how to balance the needs of stakeholders.

Highlighted Challenges:

- There is need for standardized local/regional/national planning criteria and standards for safety, resiliency, and efficiency of autonomous applications that should be shaped around functional equivalencies
- Digitalization of existing logbooks, data, etc.

- Several presenters mentioned a lack of domestic designated testing facilities for maritime autonomous applications.
- Current regulations and laws must be amended as to not impede autonomous technology and advance human assisted automation
- As technology advances, there will be a need for updated training curriculums and worker skillsets within maritime institutions
- Data access, standardization and interoperability are key and can be made possible through increased international, interagency, and industry collaborative partnerships
- Cyber security of autonomous systems and underlying technology is a glaring gap that must be addressed
- Direct, indirect, short term, and long-term socio-economic effects of automation in the maritime sector are unknown
- Research to improve integration of the many different types of sensors required for autonomous functions and "decisions"

Promising Emerging Technologies

There are many promising emergent technologies including but not limited to: terminal simulation and emulation, and auto-straddle carriers. Increases in terminal electrification may spur automation. Existing technology such as Automatic Identification Systems (AIS) can be improved and updated to develop more accurate forecasting and environmental conditions. Current maritime innovations in Europe include alternative fuels, digital advances with sensors and automation regarding vessel operations. Electronic navigational tracking and electronic charts contribute to safety of inland waterway transport, and increased autonomy implemented to complete dangerous or monotonous maritime tasks such as automated mooring is a possibility within the near future.

Highlighted Potential Emerging Technologies:

- Increase in computing power, leveraging big data and new information to support automation
- Improved communications for remote access
- Decision aids for communications in autonomy
- Sensing technologies
- Technologies dealing with the dull, dirty, and dangerous
- Artificial Intelligence/assistive technologies to reduce responsibilities leading to fatigue/overwork
- Digital twin technology

Opportunities where Government Agencies can focus to support enabling autonomy

When research and development challenges abound, so do opportunities for improvement. One moderator even mentioned that advances in autonomous technology could pave the way for another transportation revolution. New technology can increase safety for mariners and port workers, reduce accidents from human errors, optimize supply chain efficiency, and provide for improved working conditions. Monotonous maritime tasks could be replaced by autonomous technologies. Weather and environmental forecasting could become more accurate and informational, and supply chains more efficient.

Within the U.S., there is an opportunity to pursue or support a dedicated, collaborative partnership between multiple stakeholders to address challenges and research and development needs holistically. The U.S. can learn from partnerships like the Norwegian maritime cluster[3] to implement similar initiatives domestically. Collaborative partnerships and trust among partners (including between federal agencies) is recommended to improve gaps within autonomous technology. Data standardization and interoperability among agencies should be focused upon for a multi-pronged approach to autonomous technology improvements and implementation.

Highlighted Opportunities:

- Public/private collaboration to serve as a catalyst for maritime autonomous development, improving data standardization and interoperability and focused research funding and development
- Assisted autonomy can improve safety of shipping by completing monotonous or dangerous tasks including docking
- Autonomous technology could improve efficiency of supply chains by improving port operations and more
- With autonomy, transition and evolution of duties and skills inevitable, opens new doors for different work environments that could lead to better quality of life, safer ships, and overall social and economic benefits
- Automated Information Systems (AIS) could turn ships into sensors to improve weather forecasting for all users, with additional possibilities for bathymetry charting and other environmental data.
- Focus on maritime autonomy development can improve data sharing and information between federal agencies
- Foster formative platforms and collaborative groups among stakeholders for innovative and effective research and development (European model)
- Improve data access to private sector
- Standard local/regional/national planning criteria and standards for safety, and efficiency
- Reduce human error and accidents, decrease costs of shipped goods, and optimize supply chain efficiency

[3] https://maritimpolitikk.no/en/2021/norwegian-maritime-cluster

Research and Development Needs from Federal Agencies

Autonomous technology within the MTS has advanced rapidly in recent years, though increased focus on research and development is necessary to overcome maritime autonomous implementation impediments. Existing regulations, guidelines and standards are largely not applicable and must be amended and improved for safe integration of autonomous and automated technology within the MTS. The American Bureau of Shipping (ABS) is developing guidance on the application of autonomous and remote-control functions within the MTS, while the International Maritime Organization has undergone scoping exercises to improve regulatory framework for maritime autonomous surface ships[4,5]. One speaker noted that due to current U.S. regulations, vessel operators are required to keep physical logbooks, not digital, even though digital logbooks would provide underlying data that could advance human assisted automation and improve machine learning. Several conference participants also noted that dedicated marine autonomous vessels and applications testing areas in the U.S. may serve as a catalyst for research and development. Federal agencies may prepare and develop guidance based on functional equivalencies for autonomous vessels. Automated vessel navigational protocols, communications standards, and more will need to be addressed for the security and safety of the MTS.

In this regard, the United States can learn from European countries, particularly related to "maritime cluster" frameworks and innovation. The development of the Norwegian maritime cluster as a partnership between industry, government, and academic stakeholders has fostered autonomous innovation through collaborative data sharing and interoperability, testing of autonomous technology, and project funding[6]. Collaborative partnerships such as these are crucial to technological innovations and widespread acceptance of new technologies across transportation modes. A systematic approach to autonomous implementation including shipping applications, port infrastructure, surface transportation, warehousing, and more is needed for full benefits to be realized.

Alongside improved updated regulations, testing, and collaborative partnerships, perhaps the most crucial element that is not well understood is the socio-economic trade off or consequence of increased automation in the maritime sector. Autonomous technology must not be implemented at the expense of social equity, and keeping the human element is crucial for continuity of the MTS alongside increased autonomous applications. Low tech, human driven solutions will be needed when autonomous incidents, or a black swan event occurs. Local communities and labor groups should be consulted to understand how to best transition, retain workforce, and how to balance the needs of all stakeholders. New skillsets will be needed to support and maintain autonomous applications – will the existing workforce be able

[4] https://ww2.eagle.org/en/news/press-room/abs-publishes-guidance-on-the-application-of-autonomous-functions.html
[5] https://www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx
[6] https://www.offshore-energy.biz/autonomous-ship-project-bankrolled-by-eu/

to transition? How many jobs will be lost or gained? What do the maritime academies need to focus on as to produce a supportive and knowledgeable workforce?

Highlighted R & D needs that government agencies need to focus on to support adoption and implementation of these technologies:

- Review, revise, and update regulation, standards and guidance to prepare and enable increased autonomous and automated applications within our waterways and ports, to include safety and effective interactions between tradition maritime operations and evolving autonomous and automated technologies.
- Federal efforts should lean into collaborative partnerships with multiple stakeholders to focus on underlying technology for autonomous innovations similar to the Norwegian maritime cluster with partnerships between industry, government, and academic stakeholders to foster data sharing and interoperability, testing of autonomous technology, and project funding.
- A recommendation was made suggesting a designated testing area should be identified in the U.S. to support autonomous development and avoid waterway conflicts, with local and federal oversite.
- Cybersecurity improvements are necessary before full autonomy can be implemented
- Improve data products and interoperability as a foundational enabler of autonomous and automated technology for the MTS needs to be a priority. Research is needed to improve sensor integration and data delivery to support implementation and operation of these technologies.
- Priority needs for research and development include turning data into actionable information and building up baseline observations to inform future artificial intelligence and machine learning efforts. This also include development and application of Digital Twins for both shipboard and MTS utilization and applications, as well as digitization of logbooks, vessel sign on/sign off processing, credentialing, customs processing, and others.
- Research in education and training for developing automated and autonomous technologies, associated skills, competencies, and assessments is critical to its safe and effective applications.
- Research to understand what the socio-economic tradeoffs of increased autonomous applications in the MTS and to identify education and training need for effective application of these technologies. This would include cost benefit analysis, social economic benefits, safety, and labor/workforce implications.

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