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The Relevance of Resilience Engineering and Community Resilience for Future Maritime Transport Systems

Trine Marie Stene

Technological Department, SINTEF, Norway. E-mail: trine.m.stene@sintef.no

Trond Kongsvik

Department of Industrial Economics and Technology Management, NTNU, Norway. E-mail: trond.kongsvik@ntnu.no

Maritime transport systems are becoming increasingly interconnected, automated, and complex. This paper presents the MARMAN (Maritime Resilience Management of an Integrated Transport System) project financed by the Norwegian research council for the period from 2021 to 2024. Implementation automated vessels will increase the complexity, change the interconnection between actors and change ways of working. Resilience is one of the main theoretical approaches in the project. Even though resilience perspectives are relatively new in safety studies, the resilience concept is increasingly reported in safety studies and literature. The resilience concept is used in different contexts, such as healthcare, aviation, chemical and petrochemical industry, nuclear power plants, and railways. The concept represents a proactive management approach and principles for handling both normal operations and unexpected events. There are differences between the organisational practices between countries and sectors. This includes emphasizing different aspects and variables.

The purpose of this paper is to develop an initial framework addressing future challenges when implementing autonomous vessels in maritime transport systems. Resilience Engineering and Community Resilience are used as theoretical perspectives.

Keywords: Resilience Engineering, Community Resilience, Maritime Transport Systems, Autonomy, Automation, Ports and terminals.

1. Introduction

Maritime transport systems (MTS) are becoming increasingly interconnected, automated, and complex. The implementation of connected and autonomous vessels will increase the complexity, change the interconnection between actors and change the way of working (Stene & Fjørtoft, 2020). Automation will cover both autonomous vessels (MASS – Maritime Autonomous Surface Ships) and vessels with different degrees of autonomy, in addition to implementation of various Intelligent Communication Systems (ICS). However, no systematic documentation of potentials in autonomous transport systems regarding resilience are currently available (Schröder-Hinrichs et al, 2016).

The resilience concept is used in different contexts, such as healthcare, aviation, chemical and petrochemical industry, nuclear power plants, and railways. The contexts and organisational practices may differ between countries and sectors. The purpose of this paper is to develop an initial framework addressing future challenges when implementing autonomous vessels in the MTS.

2. Theoretical perspectives

The concept of resilience is important and characterized as hyper-popular in later years (Woods, 2015). A variety of definitions are used, and it is applied in different research areas. Several frameworks and theoretical perspectives are related to innovation processes.

The resilience concept represents a proactive management approach and principles for handling both normal operations and unexpected events when implementing e.g. new technology. Further, the resilience concept is represented in several approaches and perspectives. Thus, different approaches may vary regarding which aspects, variables and processes they emphasize.

This paper focuses primarily on two approaches for studying resilience: Community Resilience (CR) and Resilience Engineering (RE). The intention is to compare the two resilience disciplines/approaches, to constitute a common framework for studying innovations in the maritime transport system (MTS).

2.1. Resilience Engineering

Resilience Engineering (RE) is a new paradigm for safety management that focuses on management of normal daily operations and disaster management. RE was in the early 2000s proposed as a contrast to conventional safety approaches. During the years change in definitions has broaden the scope of resilient performance. Resilience is not only about avoiding failures and breakdowns, or the opposite of a lack of safety (Hollnagel, 2019). He argues that it is not just to be able to recover from threats and stresses, but also to be able to perform as needed under a variety of conditions – and to respond appropriately to both disturbances and opportunities. Resilience is about how systems perform, not just about how they remain safe.

Woods & Hollnagel (2006) describe RE as the capacity of systems and organizations to anticipate and adapt to changes and the potential for surprise and failure. A system is resilient if it can adjust its functioning prior to, during, or following events (changes, disturbances, and opportunities), and thereby sustain required operations under both expected and unexpected conditions (Hollnagel, 2019).

Righi, Saurin & Wachs (2015) present a literature review of resilience engineering (RE) research. Some of their results are summarizes below.

2.1.1. Safety management

RE has been advocated as a new safety management paradigm, compatible with the nature of complex socio-technical systems (CSS). Existing approaches based on accident models could not always be applicable to CCSs.

Resilience engineering could be an important supplement, involving concepts such as adaptive capacity and variability. Some variability is unavoidable and beneficial, and thus should be managed rather dampened.

Righi, Saurin & Wachs (ibid) argue that RE theory mostly is about the development of safety management theory. The first publications mentioning the term RE can be traced back to 2003. Publications from the 1st RE Symposium in Sweden in 2004 made RE more widely known to the academic community.

As a safety management theory, core objectives of RE may be to support the management of trade-offs between safety and productivity, measure resilience, and develop mechanisms to promote resilience in organisations.

Referring to Beck et al (2008), RE theory could be applied at three levels: individual, team and organisation. While most research often cover activities of front-line workers, how resilience is linked across the three levels are not well understood.

2.1.2. Research domains and areas

Further, Righi, Saurin & Wachs (ibid) present five domains accounting for 3/4 of the research on RE: aviation, healthcare, chemical and petrochemical industry, nuclear power plants, and railways. In addition several studies are made regarding transport areas as road and maritime.

All domains are characterised by complexity and hazardous technologies. All studies focus on risk management; mainly personal and process safety-related risks. Some focus on types of risk, e.g. cyber security, or natural disasters.

Six research areas are identified:

- Theory of RE (More than half of the studies; indicating an emphasize on describing of how resilient performance occurs)
- Identification and classification of resilience
- Safety management tools
- Analysis of accidents
- Risk assessment
- Training

2.2. Community Resilience

Globally, natural hazards due to climate change have received more attention, e.g. weather related to hazards as storms, floods, and landslides. To minimize the impact of any natural hazard event on human or build environments, the ability of local communities to handle these is of vital importance. This capability is commonly referred to as community resilience.

Community resilience generally refers to the ability of localised areas (usually geographically defined areas) to respond, cope and adapt to change through communal actions (Cretney, 2015). It also assumes building on and learning from existing success stories (Cutter et al, 2013).

Community resilience is highly contextual, emphasizing the importance of the local-level preparedness and resources.

2.2.1. Disaster management

The idea of resilience has only recently been adopted as a new paradigm in the disaster management community (Scherzer et al, 2019). There has been a noticeable shift in the rhetoric about hazards, moving from disaster vulnerability to disaster resilience, the latter viewed as a more proactive and positive expression of community engagement with natural hazard reduction (Cretney, 2015),

Disaster resilience can be understood as "the ability of individuals, communities, organisations or countries exposed to disasters and crisis and underlying vulnerabilities to anticipate, reduce the impact of, cope with, and recover from the effects of shocks and stresses without compromising their long-term prospects" (Scherzer et al, 2019).

2.2.2. Research domains

Community resilience starts with the premise that resilience is an integrated approach, not one based on a single system, sector, or discipline (Cutter et al, 2013). They argue that in the same way that disasters are local, so too is the need for building capacity for resilience at the local level. Further, in addition to local engagement, the federal government plays a pivotal role in providing guidance for policy and program development and necessary data and information to assist local communities. A coordinating strategy is needed.

No single entity or sector has the ultimate responsibility for creating the physical foundation for resilience. To increase resilience, shared responsibilities by individuals, families, communities, the private sector, faith-based organizations, nongovernment organizations, academe, and all levels of government are significant (Ibid.).

2.2.3. Research areas

Even though several studies are related to natural hazards, the local community must also be prepared and have resources to meet diverse threats, including terrorist attacks, and fatigued farmland. Research emphasises the importance of resources, participation, and engagement in order to build strong and engaged communities both in times of normality and disaster (Cretney, 2015).

Scherzer et al (2019) have constructed a community resilience index based on a geographical approach. The index is comprising six thematic areas:

- *Environmental resilience* (e.g. natural flood buffer, food security)
- *Institutional resilience* (e.g. resources for fire and accident prevention, financial health, proximity to airport or hospital)
- *Infrastructure and housing resilience* (e.g. housing quality, evaluation capacity, road safety, proximity to airport or hospital)
- *Social resilience* (e.g. age distribution, educational level)
- *Community capital* is relevant to social resilience but kept separate to highlight capabilities in the whole community (e.g. sources of innovation, children, broadcasters, voluntary organisations)
- *Economic resilience* (e.g. employment rate, number of firms, access to resources)

Cretney (2015) refers to other several frameworks suggesting indicators of community resilience. Most of them are included in the above index. In addition some emphasize significant indicators based on social actions and processes as:

- Development and engagement of community resources/ Engagement in decision making
- Active agents/ Knowledge, skills, and learning
- Collective action/ Participation in disaster response and recovery/ Information and communication

- Strategic action/ Engaged governance

Cretney (Ibid) categorize the literature into four commonly action factors; two related to pre-existing activities to an event/disaster (coping and response capabilities) and two related to ongoing adaptive capabilities as the situation evolves. Coping and response capabilities cover (a) Social support and (b) Social participation. Adaptive capabilities include (c) Social memory and (d) Social learning.

3. Implementation of autonomous vessels

Maritime transport systems are becoming increasingly interconnected, automated, and complex.

3.1. The MARMAN project

Autonomy is expected to cause significant changes to the Maritime Transport System (MTS). As a response to this, the MARMAN (Maritime Resilience Management of an Integrated Transport System) will explore how RE perspective, representing a proactive management approach and principles for handling both normal operations and unexpected events, can be applied to ensure the reliability of MTS.

The three-year project (2021 – 2024) focuses on implementation and application of vessels with different levels of automation. The overall objective or vision is "*to enable resilient, safe and efficient planning, management and operations of an automated integrated transport system in a complex future*". Further, the project will explore what forms of regulatory, managerial, and operational competencies that will be needed when faced with increased connectivity and automation.

A central issue is to develop knowledge to understand and manage potential brittleness and risks, and how the MTS can prepare for uncertainty and the unknown when planning and executing transports.

3.2. An initial framework addressing future challenges

The whole MTS is of interest, including actors at sea, actors in ports and terminals, and the integrations within and between the system. One aspect is interactions between technology (automated vessel) and humans (e.g. pilots of conventional vessels) and management (e.g. control centres).

Particular attention is on laws and regulations, integrated planning between the transport modes, at different management levels (from government to operational practise), work practices in the sharp and blunt end, and the interrelations between the levels.

This section summarizes relevant work packages (WPs) in the project and relevant research areas from the RE and community resilience approaches.

3.2.1. The integrated maritime transport system (MTS)

This WP will develop an <u>integrated planning (IPL) model</u> for maritime transport systems. Based on experiences from the petroleum sector. The model includes factors regarding human and cultural capabilities (the 4C's: Competence, Commitment, Collaboration and Continuous learning). The IPL model also points to enabling capacities as roles and processes, ICT, and arenas for collaboration.

Resilience perspectives on planning practices are new elements. Resilience may help identifying criticalities within the MTS. The most relevant research areas from RE are:

- Safety management tools
- Analysis of accidents
- Risk assessment

Community resilience areas of particular importance are:

- Environmental resilience
- Institutional resilience
- Infrastructure and housing resilience
- Community capital
- Engagement in decision making
- Knowledge, skills, and learning
- Collective action/ Participation in disaster response and recovery/ Information and communication
- Strategic action/ Engaged governance

3.2.2. Maritime sea leg: On board and control centre practices

This WP will develop a <u>methodology</u> for resilience mapping of the relationship between <u>on board and control centres</u> practices. This includes knowledge of the relationship between the RE concepts Work as Imagined (WAI) and Work as actually Done (WAD) on board. Further, the role of professional competence, seamanship, and resilience skills in the context of automated vessels will be studied. This includes current management and operational practice and future requirements due implementation of MASS in addition to conventional vessels.

The most relevant research areas from RE are:

- Theory of RE

- Identification and classification of resilience
- Training

Community resilience areas of particular importance are:

- Institutional resilience
- Infrastructure and housing resilience
- Social resilience
- Engagement in decision making
- Active agents/ Knowledge, skills, and learning
- Collective action/ Participation in disaster response and recovery/ Information and communication
- Strategic action/ Engaged governance

3.2.3. Port and terminals: Onshore management practices

This WP will develop a methodology for empirical analysis of port and terminal perspectives (guidelines and tools for risk assessment).

Ports and terminals are central nodes in a MTS. Insight in requirements and vulnerabilities related to communication and coordination are significant. This includes potential threats and possibilities for port and terminals when introducing more autonomous systems. To be able to perform a risk assessment for port and terminals it will be important to understand the role in a total logistics perspective, where both landside and seaside is elaborated.

The most relevant research areas from RE are:

- Identification and classification of resilience
- Analysis of accidents
- Risk assessment
- Training

Community resilience areas of particular importance are:

- Environmental resilience
- Institutional resilience
- Infrastructure and housing resilience
- Social resilience
- Community capital
- Economic resilience
- Development and engagement of community resources
- Knowledge, skills, and learning
- Collective action/ Participation in disaster response and recovery/ Information and communication
- Strategic action/ Engaged governance

3.2.4. Across sectors and countries: Socio-technical practices

This WP will develop socio-technical measures to improve safety and resilience and how these may reduce risks.

There are huge differences between the organisational practices between countries and sectors. Insight of recently RE approaches and results from other sectors are important.

The most relevant research areas from RE are:

- Identification and classification of resilience
- Safety management tools
- Analysis of accidents
- Risk assessment

Community resilience areas of particular importance are:

- Environmental resilience
- Infrastructure and housing resilience
- Social resilience
- Development and engagement of community resources
- Active agents/ Knowledge, skills, and learning
- Collective action/ Participation in disaster response and recovery/ Information and communication
- Strategic action/ Engaged governance

3.3. Concluding remarks

Both RE and CR are clearly of relevance for the MARMAN project. The scope of the project is integrated transport systems, which can be studied on different levels. One level is the individual ships, ports, terminals, and control centres, where especially RE has a richness of theories and concepts, and also tools and training schemes that can be applied. The integration of the individual organizations makes it possible to view them as communities, as they cooperate over time and sometimes need to act as a collective, for example in emergency situations. RE and CR can thus complementary perspectives for the MARMAN project and be a starting point for different activities within the different WPs.

4. Discussion

4.1. What resilient perspectives are relevant for studying maritime transport?

This paper covers two resilient perspectives – Resilience Engineering (RE) and Community resilience. While RE studies often focus on one sector or comparison of sectors, Community resilience studies represent an integrated approach, not one based on a single system, sector, or discipline.

The MARMAN project covers resilience in the maritime sector, and can benefit from RE theory, methodology and experiences from other domains.

However, the review indicates that the community resilience approach may bring in additional, relevant indicators and components. Context and characteristics of a local community is emphasized, and thus should be studied (Figure 1).

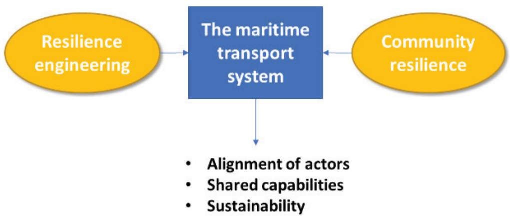

Figure 1. The integration of Resilience engineering and Community resilience actors.

For the study of automated and integrated transport systems, there is a need for analytical tools for both single organizations, and for how single organizations can be aligned for collective actions in for example emergency situations. Both RE and CR provide such tools that we will attempt to integrate. This implies that there is a need for shared capabilities in an automated maritime transport system, e.g. on how to assess risk, how to apply tools in the management of safety. Learning and training of such capabilities is addressed both by RE and CR, although with different content and focus.

Further relating to the MARMAN project, we argue that general safety and reliability factors should be included. In addition, the project should also study characteristics of at least one local (geographical territory) maritime system, including both sea legand ports and terminals.

The project should also include potential measures related to implementation of automated and autonomous vessels. From a socio-technical perspective, these should cover both technical, human, and organisational issues, and draw on both RE and CR perspectives.

4.2. Integrated planning in the Maritime domain

The MARMAN project integrates a model from the petroleum industry with perspectives on resilience. Management on strategic, tactical and operational levels are emphasized. Both safety management from RE and disaster management from community resilience literature may give significant contributions. At the higher levels, new regulations and laws (work-as-imagined) are important when implementing more automation and MASS to the maritime system. Further, operational management and management of first responders are crucial for resilience. Combining RE and community resilience may give some essential new insight, as they cover several important research areas and key performance areas.

4.3. Methods for risk assessment of Maritime Transport

Methods for measuring contextual factors as indicated by community resilience will be included in addition to traditional RE factors. There is a need to move beyond responding to the crisis of the moment, and work collaboratively to manage our risks and enhance resilience for all sectors and all communities (Cutter et al, 2013).

However, one challenge is to operationalize the factors to valid and reliable measures and methods. Community resilience based on an organisational approach and structure has created a successful strategy for encouraging and resourcing community resilience to disaster events (Cretney, 2015).

Further, it will be important to develop some baseline for assessing resilience and gather relevant data/ information in order to monitor progress.

4.4. Sustainability

Sustainability reflects long-term values or goals for life on Earth, balancing our needs without harming other people, future generations, or nature.

Sustainable development is the overarching paradigm of the United Nations (UN) and are expressed in Sustainable Development Goals (SDGs).

Global challenges address *three key dimensions/ areas of sustainable development* for achieving the SDGs – based on the 1987 Bruntland Commission Report – (1) society, (2) economy, (3) environment and climate. These considerations should be balanced in the pursuit of an improved quality of life.

Generally, RE perspectives emphasize the first of these dimensions; the society. Many RE studies focus on man-made changes, and the consequences this have on safety, including prevention and handling of accidents/ incidents contributing to injuries and death.

In addition to this, Community resilience cover natural hazards related to climate change. Community Resilience address all three dimensions of sustainable development. This perspective is often related to a defined geographical area, and challenges related to the local community.

Education for Sustainable Development has been integrated into many global frameworks and conventions related to key areas of sustainable development, e.g. disaster risk reduction, and climate change.

4.5. Conclusions

The applications of resilience in relation to safety is to a large extent based on contributions from resilience engineering. However, the concept of resilience is not uniform, and is defined and used differently in different domains. In this paper, community resilience is presented. For analysing automated and integrated transport systems, community resilience may be of relevance, as such systems involve several locations and local actors that preferably should be aligned when handling both normal operations and emergencies. The possibilities that different conceptualizations can provide will be further explored in the MARMAN project.

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