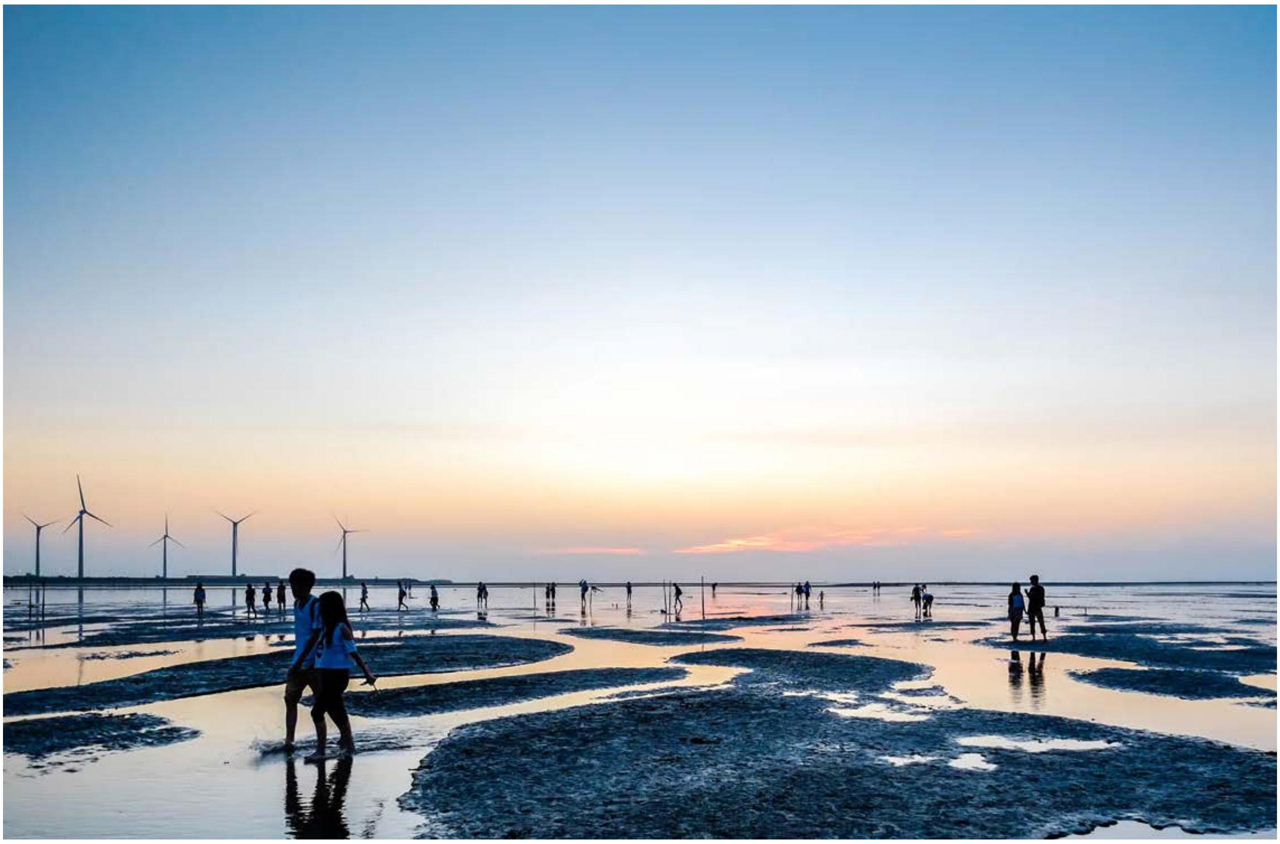
THE RESILIENCE SHIFT

Exploring Resilience in Aviation and Maritime Transport – And How Human Factors Can Help

Agenda Setting Scoping Studies Summary Report



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Introduction

This document describes the method and outcomes of a critical approach to the resilience maturity and readiness in aviation and maritime global transportation infrastructure sectors. It also provides 'agenda setting' recommendations for the future of the Resilience Shift program.

We assembled the perspectives of academic and industry authors, practitioners, stakeholders and the collective experience of the project team to generate evidence-based recommendations. These are focused in aviation and maritime sectors, but are likely to be applicable to other sectors and the overarching pursuit of resilience as a mature, useful, usable and relevant capability in the future.

In total, 73 documents were reviewed (38 aviation, 35 maritime) and 21 people were interviewed (10 aviation, 11 maritime) during the project.

Main Findings

Three quotes below summarize the review. The first poses a fundamental question to the theoretical and practical readiness of resilience – the answer is clear: not yet. The second adroitly summarizes the practicalities the resilience discipline must address for operationalization. The final quote demonstrates the clear recognition of humans as both enactors of resilience, and as the beneficiaries of resilience.

> *"Is resilience ready for the industry (i.e. usability of concepts / fitness for purpose), and is the industry ready for resilience (i.e. individually and structurally able to adopt, implement and sustain resilient capabilities)" – Adapted from Zimmermann, Paries, Amalberti & Hummerdal (2010)*

> *"I need to know what to do on a Monday morning with 6000 engineers and 4000 pilots to make things better. If it doesn't tell me that I can't use it." – Interviewee*

> *"[Resilience is] fundamental. There are different forms of cultural transition required for operators to be effective with a resilience system, but also for seafarers to be individually resilient – they won't break down as they are tired, confused etc. in the face of disruption. The global aim is to get cultures to understand that people are not commodities – the human element." – Interviewee*

The Resilience Shift research themes link

The JPRE Terms of Reference (TOR) defined five themes under which the objectives of the work program may be aligned. The work program addressed three of these themes as defined in Table 1.

Table 1. Work programme alignment with JPRE TOR themes

Theme	Link description
No. 2. Tools and processes to value resilience and ensure that value is realized through the project life	Establish evidence from a critical literature review and interviews the existence and practice of tools and processes in aviation and maritime domains, and how they influence behaviour in the sector
No. 4. Systems-thinking and resilience into existing engineering education, and new courses focused on 'resilience engineering'.	Identify need for competence development (i.e. knowledge, skills, attitudes and behaviors) stakeholders to support the instigation, implementation and governance of resilient capabilities1
No. 5. Transformative technologies that facilitate critical system functionality	Establish the contribution of HF as a transformative technology to develop new resilient capabilities in socio-technical systems

[1] This aligns the work with the LR Foundation's Foresight Review of Resilience Engineering (2015) which stating that the research priorities should "not be viewed in isolation" and "are interlinked"

Human factors - lessons for resilience integration

HF provides a fundamental technical input into the design, implementation and management of resilient capabilities to ensure appropriate assumptions are made about the contribution and limits of human performance in systems. The evolution of the HF discipline is also a useful case study for resilience to understand how resilience theory and practice may gain traction and acceptance by practitioners through effective governance and process development.

Industry adoption of human factors

Stakeholder awareness of the HF discipline has traditionally been low. People are unaware about its existence, the knowledge it accesses, why it emerged, and what it has to offer in terms of optimizing system performance and minimizing harm. This makes for a comparatively uneven playing field with other more familiar domains.

In defense, rail, oil and gas, nuclear, aviation and medical industries now require that HF be incorporated. HF integration (HFI) has been achieved almost exclusively by the adoption of regulation that mandates and governs HF activities, supported by active engagement and collaboration with other disciplines.

HFI processes are specifically designed to dovetail into engineering design lifecycles (e.g. CADMID) (see Figure 1). They also are aligned with requirements-based engineering approaches that demand usable and verifiable HF requirements generated. During operation, HF principles have been enshrined in workload, safety and fatigue risk management systems, along with competence management processes (e.g. EASA Part 145 training for aircraft maintenance personnel), providing a model for resilience to follow.

Justifying human factors and resilient capability development

Like resilience, HF is an investment in socio-technical system performance over its lifecycle. It is helpful and appropriate to be able to justify an investment in resilience in some way, including, but certainly not limited to, financial impact. Extensive studies have been summarized to assess the cost-benefit of HFI over a project lifecycle, using methodologies potentially relevant for resilience. These show an up to a remarkable 40:1 return on HF investment (Burgess-Limerick, Cotea, & Pietrzak, 2010). This demonstrates the both of the value resilient systems could benefit from through HFI, and provides methodologies that people wishing to investigate the cost-benefit of resilience could adopt.

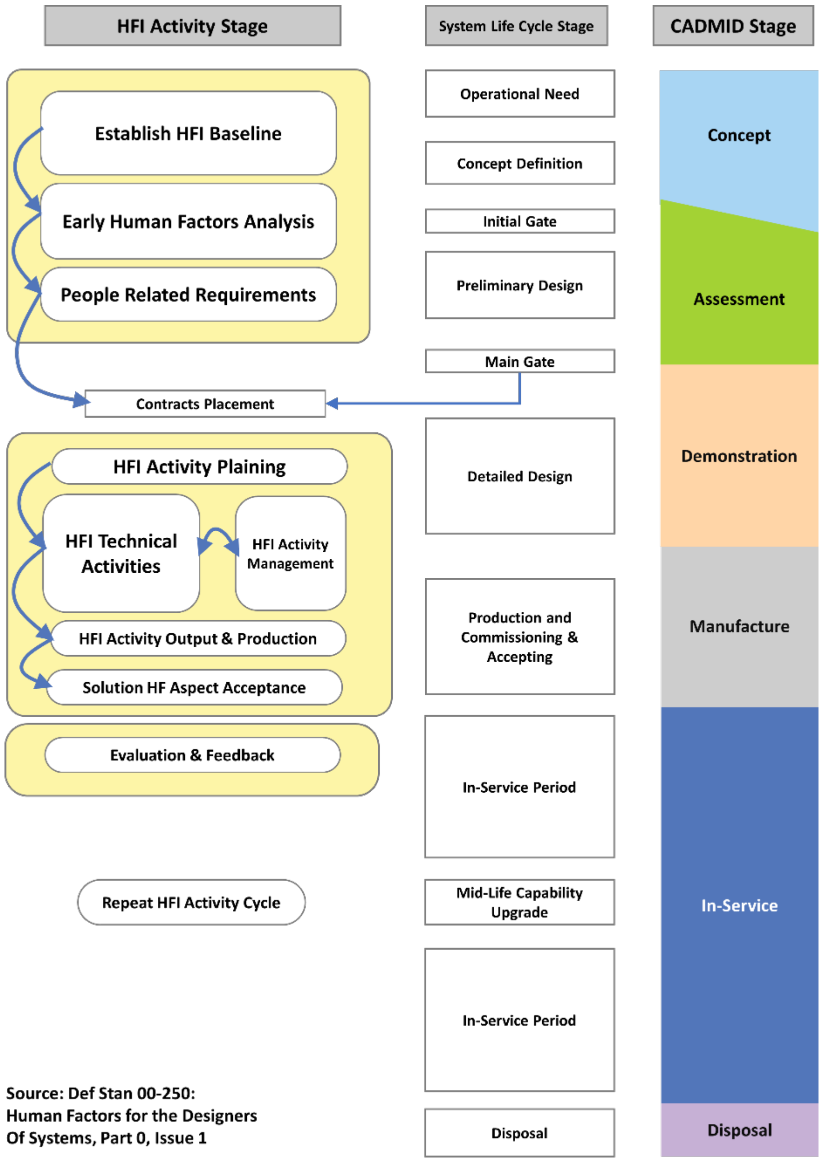

Figure 1. HFI acquisition and design lifecycle (Human Factors Integration Defence Technology Centre, 2010)

Human factors lessons learned summary

The acceptance of adoption of resilience will be dependent on developing an implementable model that is workable for the resources, technology, processes and regulatory structure of the sector coupled with effective engagement and change management.

Based on HF as a discipline Figure 2, offers the elements of a unified, usable and coherent discipline (see Figure 2) – a need echoed by interviewees across sectors to aid engagement and uptake.

Figure 2. General dimensions of HF discipline adapted for resilience (adapted from Karwowski (2012))

An important lesson from HF is the necessity to take a respectful and user-centered approach to stakeholder engagement. Understanding what matters to key stakeholders in their roles is critical to enable resilience to be offered in a way that aligns to their aims, objectives and remit, and avoids them rejecting resilience out of hand.

Human factors – a transformative technology

The objective of HF is “to understand the interactions between people and everything that surrounds us and based on such knowledge to optimize the human well-being and overall system performance” (Karwowski, 2012).

As such, HF must be considered a ‘transformative technology’ in the development of systems capable of resilient performance. It is based on the recognition that due to the current relative rigidity and brittleness of engineered systems, humans provide the primary adaptive capacity within any system, especially for unforeseen events. This requires activities in different technical areas (Figure 3).

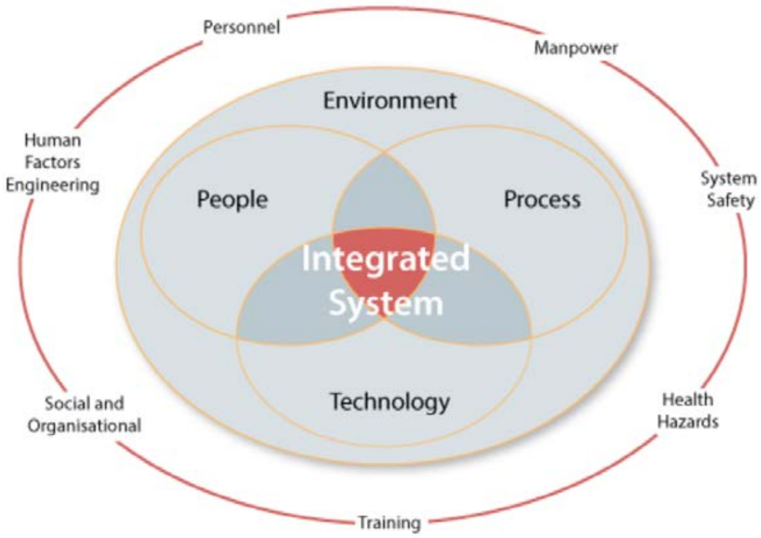

Figure 3. HFI overview (UK Ministry of Defence (2016) cited in SEA (2016))

In resilience, Hollnagel (2012) specifically recognized the human role in positive system performance when discussing the concepts of Safety-I: avoiding things that go wrong through reactive safety management; and Safety-II: ensuring things go right through proactive safety management.

Literature review & gap analysis

Literature search

Literature was searched for online using search engines (e.g. Google, Bing) using general and scholarly searches, and of the Sage Journals database. Search terms included “maritime”, “marine”, “aviation”, “ship”, “shipping”, “resilience”, “resilient”.

Additional searches were made within websites of relevant agencies (e.g. IMO) the personal resources of the team. See the bibliography in Appendix A.

Literature review guidance

A guidance document was developed to enhance the consistency of the review. This provided common principles to identify evidence of resilience in documents, including those not explicitly labelled as ‘resilience’, but addressing underlying concepts.

The definition of resilience provided to the team is below, and was extended to include the RMLA capabilities (Hollnagel (2015)) Table 2) to help focus literature review.

> ***Resilience definition:*** *“The emergent property or attributes that some systems have which allows them to withstand, respond and/or adapt to a vast range of disruptive events by preserving and even enhancing critical functionality”*

Table 2. RMLA capability definitions (Hollnagel (2015))

Capability	Definition
Respond	Knowing what to do, or being able to respond to regular and irregular changes, disturbances, and opportunities by activating prepared actions or by adjusting current mode of functioning
Monitor (i.e. the present)	Knowing what to look for, or being able to monitor that which is or could seriously affect the system’s performance in the near term – positively or negatively. Monitoring covers the system’s own performance as well as what happens in the environment.
Learn	Knowing what has happened, or being able to learn from experience, in particular to learn the right lessons from the right experience – i.e. double-loop learning

Capability	Definition
Anticipate (i.e. the future)	Knowing what to expect, or being able to anticipate developments further into the future, e.g. potential disruptions, novel demands or constraints, new opportunities, changing operating conditions
Note: Adaptation is a composite of learn, respond and monitor. Preparedness is implicit in learning and anticipation.	

A quantitative analysis was performed and summarized in Table 3.

Table 3. Aviation and maritime document classification results

Characteristics	Maritime (n = 35)	Aviation (n = 38)	Maritime & Aviation (n = 73)
Resilience Literature			
'Resilience' in title / text	31 Y (4 N)	30 Y (8 N)	61 Y (12 N)
Document focus			
Theory	17 Y (18 N)	17 Y (23 N)	34 Y (41 N)
Regulation/Guidance	5 Y (30 N)	11 Y (30 N)	16 Y (60 N)
Description of current state	23 Y (12 N)	14 Y (27 N)	37 Y (39 N)
Implementation Initiative	0 Y (35 N)	20 Y (19 N)	20 Y (54 N)
Area of application			
Domain	26 Maritime	29 Aviation	8 Both
Operations	12 Sail	17 Airborne	2 Both
	7 Shore	16 Airline	
Maintenance	2 Maritime	5 Aviation	2 Both
Infrastructure	15 Harbour	7 Airport	2 Both
Traffic Management	5 VTS	13 ATM	5 Both
Transversal	9 Y	8 Y	-
Disruption readiness			
Predict & Withstand	31 Y (4 N)	22 Y (16 N)	53 Y (20 N)
Unforeseeable Events	14 Y (21 N)	28 Y (13 N)	42 Y (34 N)
Resilient Capabilities[1]			
Respond	20 Y (15 N)	23 Y (15 N)	43 Y (30 N)
Monitor	17 Y (18 N)	21 Y (17 N)	38 Y (35 N)
Learn	15 Y (20 N)	23 Y (15 N)	38 Y (35 N)

Characteristics	Maritime (n = 35)	Aviation (n = 38)	Maritime & Aviation (n = 73)
Anticipate	13 Y (22 N)	18 Y (20 N)	31 Y (42 N)
Resilience Level[2]			
Individual	14 Y (21 N)	9 Y (30 N)	23 Y (51 N)
Team	6 Y (29 N)	11 Y (30 N)	17 Y (59 N)
Multi-party	15 Y (20 N)	7 Y (34 N)	22 Y (54 N)
Organization	15 Y (20 N)	12 Y (29 N)	27 Y (49 N)
Sector	13 Y (22 N)	17 Y (23 N)	30 Y (45 N)
Inter-sector	7 Y (28 N)	5 Y (36 N)	12 Y (64 N)
[1]Hollnagel's RMLA definition of resilience (2015); [2]Resilience levels of application (Rypkema, van der Beek, Schraagen, Winkelman, & van Wijngaarden, 2015) (extended version)			

Quantitative analysis conclusions

No documents described resilience implementation initiatives. The majority of literature focused on the description of the current state, followed by a description of theory, with five covering regulatory aspects. This clearly indicates the emerging state of resilience and the theoretical approach verses a practical approach. It could also indicate the lack of industry readiness and/or the lack of maturity in the concepts for successfully implementation.

SEAHORSE contribution to resilience

SEAHORSE aimed to transfer resilience solutions technology from the aviation sector to maritime. In the current project context, the SEAHORSE database and STEM approach (see below) are potential resources that may accelerate transfer and adoption of safety-related tools that contribute to resilient performance – a need echoed by in the findings.

SEAHORSE viewed resilience as being synonymous with safety, and followed a definition of resilience adopted from Hollnagel (2015).

A database was compiled of 166 resilience 'solutions' in the aviation sector to potentially benefit the maritime sector. Seventy-three solutions were prioritized and taken forward with consideration of the SEAHORSE Resilience Model (Table 4) that ensured that a solution to improve resilience at one level does not create a negative impact on other level(s).

Table 4. SEAHORSE Resilience Model

Ability / *Level*	Anticipate	Monitor	React	Learn
Individual *Operational Demand / Resilience Resource*	New crew members needs time to familiarize --- Let new crew members express lack of experience with specific situations	Tiredness induced concentration loss --- Enhance recognition of significant change	Foreign crew members face reading challenge --- use of pictograms instead of written procedures	Lack of ship type specific knowledge --- Delta Learning
Team *Operational Demand / Resilience Resource*	Lack of team competences --- Team Dimensional Training	Reduced crew atmosphere --- Discuss information flow, initiative/ leadership, communication, supportive behaviour	Suboptimal team performance --- Support Team awareness	Blame culture on board --- Structural Debrief of good practices
Multi-party *Operational Demand / Resilience Resources*	Crews and stevedores have different safety culture --- Structured Briefings at start loading/unloading	Insufficient trust between ship and shore organisation --- Virtual social sessions	Inter-party confusions --- Introduce time outs	mutual experiences do not last --- Celebrate successful partnerships
Organisation *Operational Demand / Resilience Resource*	Economic pressure on board --- Increase awareness of negative consequences	Insufficient insight in strength of safety regime --- Registration of successful deviations from plans	Insufficient safety resources --- Resilience Model based safety investments	Underexplained accidents --- FRAM-based accident analysis

STEM – A structured approach to transferring resilience innovation across sectors

Most transfers of learning or innovation are opportunistic and ad-hoc. SEAHORSE wanted to advance an approach to transfer which would enable resilience innovations to be transferred across sectors systematically called STEM (Safety TransfEr Methodology). STEM is applicable to any 'destination' sector (Liston, Silvagni, & Ducci, 2017b). STEM three broad steps shown in Figure 4.

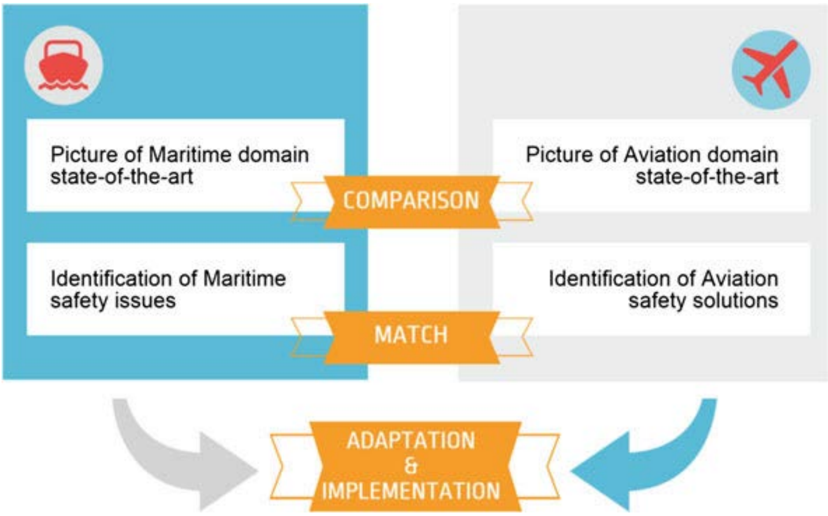

Figure 4. STEM three steps

Gap analysis interviews

This section describes the process to develop a semi-structured interview protocol to establish the penetration, practice and utility of resilience in the aviation and maritime sectors.

Interview protocol development

A standardized interview schedule was developed to elicit information from stakeholders in a semi-structured interview phone / Skype format. An initial list of questions was developed based on the literature review that was refined to 12 final questions and grouped into two sections for the interviews:

Section 1: How do stakeholders go beyond Safety-I – questions about what interviewees do in their organization.

Section 2: The resilience concept – how useful, complete and applicable the concept is from your perspective

Interviewee selection

Practitioners, academics and operational staff from the aviation and maritime sectors were identified internationally and invited to participate using a standardized email. Some candidates approached did not respond or a could not be scheduled within the constraints of the project. The consortium recognizes some unavoidable gaps in the mix and bias of interviewees. However, due to the global nature of the sectors, the 21 interviewees (10 aviation, 11 maritime) often nominated their experience as global Appendix B.

Findings

The sections below capture the combined findings from the literature review and interviews summarized under three overlapping gaps. Many commonalities emerged in their resilience readiness and maturity, and the challenges to establish sustainable capabilities.

The sector findings and quantitative data indicate that there is at least a variation, if not confusion, about the aspirations of resilient capabilities. It clearly is not satisfactory to limit the definition of 'resilience' to traditional Safety-I approaches.

A number of existing practices potentially contribute to resilient capabilities (e.g. CRM), or could be co-opted to do so.

Theory gap

Resilience literature has been well publicised and is currently receiving considerable attention, with multiple recent literature reviews elsewhere (e.g. EU project DARWIN) and ongoing (e.g. Federal Aviation Administration – FAA, IMarEST). However, this review has identified that there is a clear resilience theory gap between current literature and applied context that meant it **has not yet**:

- **Penetrated industry practice:** literature is too theoretical with very little practitioner uptake
- **Adequately taken account of existing best practice in achieving resilience** including practices not always labelled 'resilience' and Safety I contributions which have arguably been successful
- **Become complete as a theory or as a discipline** with no unifying underlying theory to resilience from which practical solutions can be developed.

There was strong agreement from interviewees that HF is a key component in a definition of resilience and fundamental to its realization.

A close relationship with sector stakeholders is needed to ensure high ecological validity of approaches from research and development, and to aid implementability.

There was recognition that resilience theory is not a panacea, e.g. tactics to enhance resilience can expose systems to common mode failure (e.g. common software systems across sites); see also Owen (2016).

In aviation and maritime sectors there is no slack in the system to deal with disruptions. Resilience has thus far failed to make a case to force this change in mindset, or incorporate these challenges into its thinking.

Definitions are varied and sometimes conflicting, but generally appear shaped to match the problem space (e.g. multi-party aspects included in port resilience definitions). The variability in may also reflect disparate, and isolated groups working to different terms of reference and different personal exposure to resilience domain.

New components and approaches are being added or co-opted to understand the challenge, e.g. moving from Safety-I to Safety-II (Hollnagel E. , 2012) FRAM (Hollnagel (2014) cited in Praetorius et al. (2014)), and control modes for different operational contexts (van Westenren, 2014).

Research to practice gap

Resilience research has mainly focused on academic dialogue applied to theoretical or case studies and on limited, localised trials of specific tools that address a small subset of the overall resilience of the situation. Research to date appears to be missing some key questions such as **how to**:

Resolve the balance between approaches optimised for normal circumstances (lean and standardised) and for disruptive situations (needing 'slack' in the system and creative flexibility) both are needed but under what circumstances is each appropriate; what advice do we give to front line operators when faced with an unexpected event for which they have had no training and no checklist and how do we make associated choices for recruitment and training of appropriate aptitudes and skills

Integrate human performance into resilience theory to define the role of humans in the system to achieve resilient performance, how to optimise this, and to ensure that what is expected of human elements is realistic and supported

Overcome the barriers to implementation such as the lack of quantifiable measures of resilience, such that commercial organisations are unable to visualise how much resilience they have now and how much more they would buy if they made an additional investment.

A user-centered approach to facilitating engagement and action on resilience from all stakeholders (including regulators and industry bodies) is required.

Resilience theory is not sufficiently mature to be readily communicated to the industry in a way for stakeholders to understand 'what's in it for me', or to recognize which problems that it would aid solving. At a practical level, even very proactive stakeholders with extensive expertise in HF and safety management who are interested in any approach to enhance the performance of their organization cannot see how to take a first step.

Development of theory to describe significant features of sectors to identify similarities and differences could support utility of future resilience application efforts (Liston, Kay, Cromie, & McDonald, 2017a), Price (2016) and Praetorius et al. (2012)).

Competence is an issue in all stakeholders at all level in terms of resilience but also in terms know how to understand their problem space to minimize unintended consequences from decision-making, and to recognize the potential benefit of resilience thinking within it (once it has been more clearly defined).

Some segments and regions support greater proactivity in stakeholders (e.g. Norwegian maritime OSV operations in oil & gas, ATC). Factors underpinning this positive situation, and their evolution need understanding to aid development of preconditions for proactivity in other segments and sectors. For example, VTS appears like a good candidate to adopt resilience as it sits at the interface of port operations (and associated infrastructure links) and to ship operations, but is unlikely as drivers to be more sophisticated and proactive are not present.

Existing practices, tools and methods can support RML functions to some extent (e.g. ISM code, STCW, surveys and vetting), but 'anticipation' functions are rare outside of financial functions.

In comparison to aviation which has very mature dissemination channels, maritime has few channels to disseminate to, engage with and actively involve stakeholders in resilience research and development, (including the important IMO). Engagement with industry bodies (e.g. Intertanko, InterManager) may be very beneficial.

The role of consultants to be able to offer new approaches to industry needs to be explicitly recognized in models to engage industry – operational personnel in both sectors are not exposed to new ideas, often due to ongoing work pressures.

In both sectors, a compliance focus, siloed decision-making and lack of HF expertise undermine adoption of proactive approaches and generate unintended consequences in organizations and sectors. Stakeholders do not understand why resilience could be is important.

Governance gap

Governance relates to the decisions made that are relevant to the research and its implementation in the industry, by getting the right information, to the right people, in the right format, to make the right decisions. Some related issues are covered above, but additional factors include the **need to**:

Support organisations to reflect, monitor and improve as they implement improvement processes which aim to develop resilient performance

Commission and provide oversight of the research, including industry involvement in defining the goals that are set for research, dissemination of outputs and encouraging applied studies of implementation;

Define the role of Regulation in developing and assuring system resilience, and how is regulation itself best made resilient. How can industry (especially maritime) be directed away from a compliance culture to take advantage of resilient capabilities?

Framework for resilience implementation

This Framework for Resilience Implementation is based on over 20 years of lessons learned in change initiatives and improvement case studies in socio-technical systems. It presented as an opportunity to the Resilience Shift programme build on to accelerate implementation of resilient capabilities across sectors.

It draws on evidence from a wide range of collaborative European Commission-funded research (e.g. HILAS, TATEM, MASCA, PROSPERO, ACROSS, TASS, SOTERIA and FutureSkySafety) focusing on functioning operational systems.

The emerging trends of this research highlighted the following critical issues that make delivering resilient performance in socio-technical systems a challenge:

Complexity: The complexity of everyday operations seems to defy systematic understanding. Too many exceptions undermine linear risk models; Emergent factors are poorly understood; Limitations of expert judgement; Too much data poorly integrated; Only the professional in situ can properly comprehend the situation. This is a problem of information and knowledge.

Efficacy: Lack of consistent follow through from identifying a problem to verifying a solution; Emphasis on compliance rather than demonstrable improvement of system performance. This is a process issue for improvement and change

Scalability: Information systems feed silos with attenuated feedback and limited local support; Operations span boundaries – risk and safety management does not; Strategic management of risk and safety performance is weak. These are problems of social relations – working with / reporting to.

These work also points to the importance of understanding information flows (and information infrastructures) at the design phase in order to build systems which can be effectively implemented in line with established HF principles (e.g. McDonald, Morrison, & Grommes (2007), McDonald, Kay, Morrison, & Ryan, (2017).

Cycle of innovation

The implementation of resilience principles and capacities requires a virtuous cycle of innovation (Figure 5).

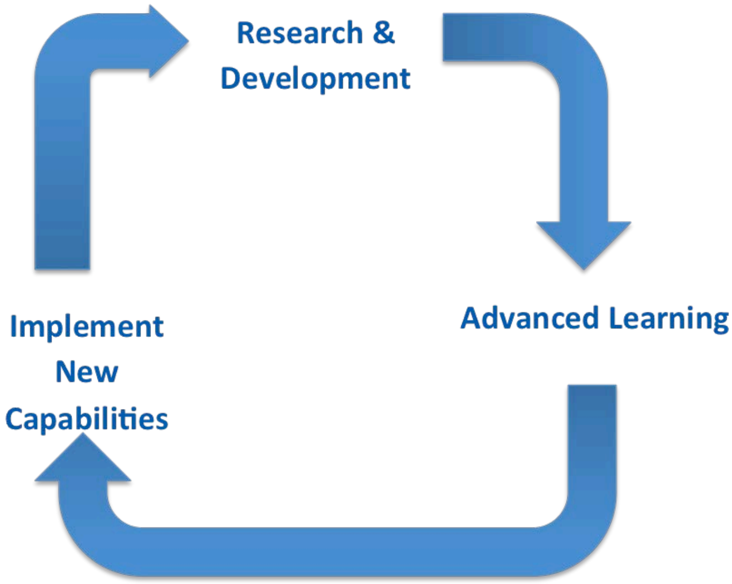

Figure 5. Cycle of innovation

Engaging stakeholders in research, academia, funding bodies and industry as a 'community of innovation, implementation and practice' is essential to:

- Translate research into practical innovations
- Transfer academic knowledge into practice
- Generate fresh research based on implementation of innovation through a 'community of practice' (CoP)

Developing capacity and competence at individual and organisational levels

Competence development and capacity building for resilience is a key part of the cycle of innovation and CoP. It relates to further education courses for stakeholders in resilience principles and the use of methodologies to make systems more resilient.

At present, there are two main types of tertiary courses that cover resilience engineering: 1. targeting full-time students; and 2. targeting practitioners who are in full-time employment and who study part-time. Those courses which target practitioners tend to be online courses to allow students to continue working, and have a more practical, implementation focus with coursework built around action research projects led by the student in their own organisations.

Courses have been identified internationally that address resilience as part of the curriculum with an online presence including: University College London (UK), University of Canterbury (NZ), University of Lund (SE), Trinity College Dublin, The University of Dublin (IE), and the University of Japan (JP).

Only the courses offered by the University of Lund and Trinity College Dublin offer online components and target professionals in a range of industries (e.g. finance, healthcare, IT, defence, emergency services, aviation, maritime, pharmaceuticals). These courses cover resilience, risk, change, operations, quality, safety, human resources, planning, and system design.

Technical elements

Understanding the operation using tools for systemic socio-technical analysis

Dedicated methods and tools for socio-technical analysis deliver ecologically valid systemic knowledge (McDonald, 2015). The research in aviation has demonstrated that large integrated operational systems typically comprise different interlocking components that represent fundamental process types. Each of these can be described in terms of the key source of variance:

Operators (e.g. airlines) deliver the core service, typically involving complex tasks done individually or in small operational teams.

Infrastructure (e.g. airport) delivers a common structure on which many operators can deliver their services, but also radically constrains how the operation and services can work.

Traffic (e.g. ATC) manages the flow of operations along or between infrastructures. Sector capacity and separation represent critical variances to be controlled.

Services (e.g. ground ops) support the operation and its interface with the infrastructure. Co-ordination of service delivery across multiple operators defines a key source of variance.

Maintenance delivered to the operator has to deal with multiple units that comprise the service (e.g. aircraft). The ratio of planned to unplanned maintenance dictates a constant uncertainty about demand and availability of resources.

Some services (e.g. safety, financial, planning) depend on an **information-rich management process.** Variance here depends on a combination of the processing of information within each task or process segment and the transfer of that information to the next stage of the process, and so on.

Finally, processes that seek to change or improve a system may be characterised by a core uncertainty about the achievement of **goals.**

It is important to understand the core sources of variance within the particular sector of the overall operation. This determines both the nature of the risk as well as the constraints and opportunities to gain leverage in promoting resilience.

Adaptation and change

Naturalistic analysis of adaptation and change in response to serious incidents reveals dominant tendencies towards cycles of stability: even in the best organisations it takes three or more serious events before an operationally valid solution is found.

Each stage of the improvement cycle is more difficult and prone to failure (problem – analysis – recommendation – implementation – evaluation). Case studies of successful change have been carried out in aircraft maintenance, airport and airline operations (Ward, McDonald, Morrison, Gaynor, & Nugent, 2010); (Corrigan & McDonald, 2015) and summarised in Table 5.

Table 5. Comparison of successful and less successful change initiatives

Factor	Typical of successful initiatives	Typical of less success
People	Engagement of all stakeholders; Dedicated well supported improvement team; Active senior management support	Not the right people Not well resourced Lack of support
Process	Common understanding of real process; Effective processes to resolve problems	Processes not understood Problems not resolved
Information & knowledge	Open approach to data & information; All in the loop who need to be; Information enhances management processes	Reluctance to share data Key people not in loop Management not on top of what is happening
Information Technology	Designed around all users. Flow and feedback of information	Large effort to develop tools that are not used

The four research areas presented above illustrate at least some basic capacities that underlie the delivery of a resilient response in diverse operational situations. These also feedback into potential competence deficits for developing resilient solutions.

Response to crisis

Research in emergency operations has developed a human-centred concept of operations (CONOPS) as a framework that can be used to analyse, develop and communicate the vision of a system and its objectives to system actors. This CONOPS approach has been used as an applied resource allowing emergency services to produce a common system vision that they can coordinate their activities around and identify the potential for change (Ross et al., 2017).

Implementation framework conclusion

The overall recommendation from this work is that there is an urgent requirement to build evidence-based case studies of implementation of resilience using a consistent, systemic methodology for both social and technical aspects. This would allow the generation of an archive of case studies that would support a meta-analysis of what works and does not work, in terms of resilience in real socio-technical systems and feed in to a CoP.

The Resilience Shift programme recommendations

This section draws together all the findings from both sectors to present a list of potential activities, projects, or clusters of projects, to address the challenges identified underlying a resilience shift – noting that resilience remains an effectively immature, unvalidated and impractical theoretical construct for both aviation and maritime, and that the case has evidently not been yet made for resilience integration, nor is it a panacea.

Activity in the 17 areas below would be generalizable outside aviation and maritime, especially to other high-hazard industries and projects.

Table 6. The Resilience Shift programme recommendations

No.	Title	Description
Overarching		
1	Develop the resilience discipline	Systematically support the development of elements of resilience as a unified, usable and coherent discipline (Figure 2).
Resilience Theory		
2	Support development of resilience theory	Resilience theory (including Safety I & Safety-II) must progress beyond system performance aspirations to a point where the effect of resilient capabilities can be demonstrated and validated (e.g. using experimentation and case studies from target sectors and other sectors where resilience is being practised e.g. community resilience, defence). Mechanisms supporting sustained system functionality during unforeseen disruptions must be identified and tested. This is predicated on theory being defined such that it can be practically implemented and/or identified in real-world systems to enable testing. In addition, the relationship with / differentiation from other related areas should be defined (e.g. emergency preparedness, safety culture, business continuity, quantitative and qualitative risk assessment methods).
3	HF integration into resilience thinking	Explicitly integrate HF into resilience thinking (at individual, team, organisational multi-party, sector and inter-sector levels) to define achievable roles for humans to play in a resilient system throughout their lifecycle (e.g. Figure 1), how they will be implemented, how to actively deploy and manage human contributions to achieve resilient performance. The relative scarcity of HF expertise in target sectors must be considered in developing an implementable approach.
4	Optimization for normal versus disrupted	Address the tension between optimization for normal operations versus optimisation for disrupted operations. Include in this the practice of frontline staff using following tightly controlled

No.	Title	Description
	operations	procedures versus the need for creative decision-making in disrupted situations, and how to understand the trade-off between the cost and logistic benefits of very lean, standardised systems with the investment in resilient performance over the project / organisation / sector lifecycle.
5	Scope extension of resilience application	Extend resilience theory beyond safety to integrate other aviation and maritime business and sector functions (e.g. financial, organisational, operational delivery and business resilience).
6	Resilience cost-benefit	Develop and perform resilience cost-benefit approaches (derived from HF and other relevant disciplines) to facilitate investment justification (links to recommendation 1).
7	Resilient mechanisms testing	Identify and Investigate the validity and utility of resilient capabilities (i.e. autonomy, self-organisation, dynamically reconfigurable systems) through case studies to identify where they have acted as mechanisms to achieve resilient system performance aspirations, where not, and why.
Research to Practice		
8	Resilience Engineering Integration (REI) and Resilience Management System (RMS)	Develop a suite of user-centred Resilience Engineering Integration (REI) and Resilience Management System (RMS) elements including: regulation, resourcing, process, methods, tools, measures (direct and indirect) and associated standards supporting project and organisational lifecycles based on the HFI and SMS models. (Note: dependent on validation outcomes in recommendation 1)
9	Dissemination & engagement pathways	Develop dissemination methods, and engagement and implementation pathways customized to the potential role, remit and readiness of different stakeholders (e.g. interactive workshops enabling individuals within stakeholders to take next steps), including distillation of useful messages for practitioners in a digestible form that they can apply in their daily jobs.
10	Competence standards for resilience	Develop a set of competence standards covering technical and non-technical skills to support resilience within key stakeholders at all internal levels to support implementation and RMLA functions. Anticipation activities and tools were shown to be weakest in this review, and the of validity of the 'weak signals' concept as a practical proactive tool needs testing.
11	Enhancing existing methods	Extend the work of SEAHORSE to identify existing methods and tools that could adopt or incorporate resilience thinking within and across sectors. Develop and validate extensions / modifications to enhance effectiveness (e.g. CRM CRM / BRM). Integrate learning from resilience integration explicit and implicit resilience-related activities highlighted herein (e.g. SESAR, Luxair)
12	Maritime-specific challenges	Investigate the impact and mitigation options for particular maritime sector challenges such vessel manning, commodification of crew, intractability of operating with risk (e.g.

No.	Title	Description
		cruise sector)
Governance		
13	Regulation for resilience	Investigate the role regulation in developing and assuring resilience, how resilient capabilities can be integrated with existing regulatory models (including Ship Classification), e.g. including safety cases, risk assessments, resilience management system. Include in this the tools available to regulators to directly mandate resilient performance, to mandate the factors underlying resilient performance (e.g. just culture), and the characteristics that make regulation itself resilient.
14	Resilience contractual guidance	Develop guidance on inter-organisational contractual relationships to support the development of resilient capabilities across stakeholders.
CoP (Community of Practice)		
15	CoP (Community of Practice) development	Support the establishment of a resilience community of practice with common processes / frameworks spanning both governance and implementation. These issues currently hinder the wider dissemination and exploitation of resilience. The Framework for Resilience Implementation provides a roadmap for implementing, evaluating and gathering evidence of the 'practice' of resilience. There needs to be an extension in resilience thinking to implementation and developing an implementation community which shares common methodologies.
16	Standardized Case-Study Analysis Framework	This requires discipline and agreement. Develop a common methodology for performing implementation projects and a common framework for analysing resilience case studies (i.e. examples of resilience implementation projects) and their impact. Resilience needs to become normalised and functional within organisations. For this to happen practitioners need access to comprehensible best practice guidelines which are shared by the entire resilience community.
17	Resilience implementation case study archive	The main opportunity posed by the Resilience Implementation CoP relates to the establishment of a database of resilience implementation case studies to see what is working and what is not (both in terms of the implementation process and the effectiveness of the resilient capability of the organisation). Having a database such as this would allow practitioners and researchers to compare and contrast and transfer learning across implementation projects.

Conclusion

Expectations about the implementation of a resilience shift must be tempered by an objective perspective of the maturity and readiness of resilience as a discipline for implementation, and the complementary maturity and readiness of aviation and maritime sectors to engage with it. Despite the explosion of work in the area over the last twenty years, it is clear that significant efforts are still required to develop, validate and package resilience theory to make it useful and usable by industry. Supporting this, a credible strategy needs to be developed to engage and build the necessary competence within the sectors to change practice in line with resilience principles.

This project emphasized that to achieve the aspirations of resilient socio-technical systems, HF must be systematically brought it at every stage as the fundamental ‘transformative technology’. Human error is offset by the performance of well-intentioned people in dysfunctional organisations – it is the human element that keeps imperfectly designed system working effectively. People are not, it turns out, the most vulnerable parts of the system.

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Glossary

ATC	Air Traffic Control
ATM	Air Traffic Management
BRM	Bridge Resource Management
CAA	Civil Aviation Authority
CMTS	U.S. Committee on the Marine Transportation System
CoP	Community of Practice
CRM	Crew Resource Management
EU	European Union
FRAM	Functional Resonance Analysis Method
IMarEST	Institute of Marine Engineering, Science & Technology
IMO	International Maritime Organisation
HF	Human Factors
JPRE	Joint Programme on Resilience Engineering
RMLA	Respond, Monitor, Learn and Anticipate
SEAHORSE	Safety Enhancements in transport by Achieving Human Orientated Resilient Shipping Environment
STEM	Safety TransfEr Methodology
VTS	Vessel Traffic Services

Appendix A: literature review documents

No.	Reference
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Appendix B: list of interviewees

Table 7. Interviewee Summary

No.	Role	Location	Region Knowledge	Knowledge Category
Maritime (n=11)				
1	Principal HF Consultant	UK	Europe, North America & Asia	Crew, Shore & Regulation
2	Organisational Development & HF Specialist – Ship Owner	Norway	Global (Singapore / USA / Denmark / India/ Phillipines)	Crew, Ship Operations, Shore
3	Senior Consultant in HF, Ship Operations Maritime Advisory	Norway	Global (Norwegian companies)	Crew, Ship Operations, Shore
4	Managing Director – Consultancy	UK	Global	Crew, Ship Operations, Shore (Tankers / oil & gas)
5	VTS Design & Specification Consultant	UK	Global	VTS
6	General Secretary – Industry Segment Body	UK	Global	Crew, Ship Operations, Shore & Regulation
7	Senior lecturer – Maritime HF	Sweden	Global	Crew, Ship Operations, Shore
8	CEO – Ship Management Company	Netherlands	Global	Crew, Ship Operations, Shore & Regulation
9	Maritime Human Element Policy Specialist	UK	Europe	Regulation
10	Researcher in Risk, Safety & Reliability	Sweden	Europe	Maritime
11	Technical Advisor -Industry Segment Body	UK	Europe	Regulation
Aviation (n=10)				
12	Airline HF Manager	UAE	Middle East	Airborne
13	Safety & Risk Management Researcher (Industrial Background)	France	Europe	Aviation (maritime familiar)
14	Airline HF Manager	Luxembourg	Europe	Training

No.	Role	Location	Region Knowledge	Knowledge Category
15	Research Scientist	Switzerland	Europe	Research
16	Project Manager System Reliability & Resilience – Industry Body	UK	Europe	Maintenance
17	Airline Training Captain	UK	Europe	Operations
18	Principal - Policy Development	UK	Europe	Regulation
29	Director of Strategy - ATC	UK	Europe	ATC
20	Chief Scientific and Technical Advisor, Flight Deck Human Factors	UK	North America	Regulation
21	Head of Safety Analysis and Performance	Germany	Europe	Regulation