

Risk analysis of innovative maritime transport solutions using the extended Failure Mode and Effects Analysis (FMEA) methodology

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ABSTRACT: With 74% of EU's international trade by volume and 51% by value being carried by sea, maritime transport and ports play a predominant role in Europe. The increasingly dynamic business environment characterizing those sectors as well as the pressing need to efficiently and sustainably cope with increasing freight volumes, are driving the continuous investigation of innovative and promising solutions, the implementation of which can provide further efficiencies to the system as a whole and to the relevant stakeholders involved. Building upon the results of an expert consultation process, undertaken within the framework of the Mobility4EU project, this paper presents a validated set of such solutions analysing, based on the extended Failure Mode and Effects Analysis (FMEA) methodology, the main risks that could potentially hinder or delay their implementation, thus providing a set of appropriate strategies and measures that can be adopted for mitigating those risks.

1 INTRODUCTION

1.1 Background

With over 80% of world's cargo by volume and 70% by value being carried by sea, maritime transport is reasonably being acknowledged as the backbone of international trade heavily supporting the global economy (UNCTAD, 2017a). Over the past four decades, maritime transport volumes have been constantly increasing at an impressive rate, with the exception of 2009 when the impact of the global financial crisis became apparent also to the maritime transport industry among several other sectors.

The European continent proves to be attracting the majority of international freight flows (Figure 1), with 74% of the respective volumes being accommodated through an extended network of 329 seaports, among which 83 represent major hubs and are thus being acknowledged as the core part of the trans-European transport network (TEN-T) (European Parliament and EU Council, 2013). In addition, short sea shipping accounts for a considerable share of intra-European trade (37%), further stressing out the increased importance of maritime transport and ports in Europe, thus their substantial contribution to the European economy.

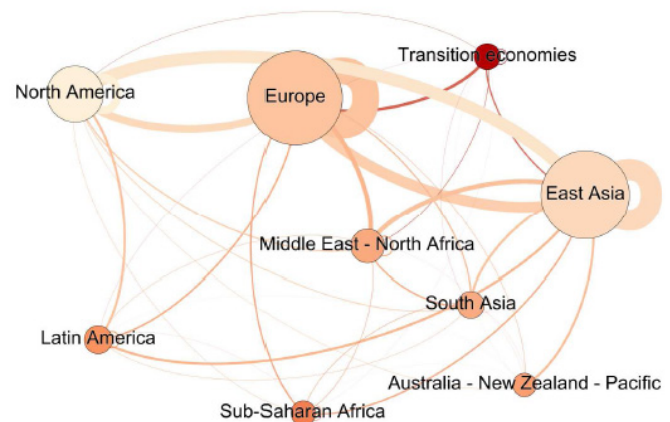


Figure 1. Trade flows across world's regions in 2015 (UNCTAD, 2017b)

Both sectors are being characterized of a highly competitive and dynamic business environment, subject to increased technology penetration (e.g. new information and communication technologies, internet of things, automation and remote-controlling, augmented reality, etc.), facing disruptions as a result of global emerging market trends and developments (e.g. increasing vessel sizes, formation of strategic shipping alliances, establishment of international terminal networks by global terminals operators, etc.) and being confronted with stricter environmental regulations coming into force (e.g. new emission limits in Sulphur Emission Con-

trol Areas, etc.), all of which prove to be significantly and rapidly changing business as it is (WATERBORNE TP, 2016). The intricate characteristics of this business environment along with the pressing need to efficiently accommodate ever increasing freight volumes, are continuously driving the investigation of new, innovative solutions (e.g. technology-, infrastructure-, policy- environment-oriented, etc.), the successful implementation and deployment of which may generate significant benefits to the system as a whole as well as to several stakeholders of the extended maritime transport and port communities.

The aforementioned considerations form the background of the EU-funded Mobility4EU project, which aims to deliver a vision for the European transport system in 2030 and an action plan, including a roadmap, for implementing that vision. The project follows a user-centeredness and cross-modality approach addressing, among other modes, waterborne transport systems covering both freight and passenger transport.

This vision and action plan of Mobility4EU is being based on the identification and assessment of societal challenges that are expected to influence future transport demand and supply, as well as on the compilation of a portfolio of emerging and promising cross-modal technical and organisational transport solutions likely to disrupt the current business environment. The entire process from studying new trends and developments, and assessing the potential of innovative transport solutions for developing the aforementioned vision and action plan, follows a structured participatory approach engaging, into the consultation process, a broad stakeholder community. For capitalizing upon these results and ensuring their sustainability, a European Transport Forum will be established at the end of the project, taking in this way a step further for efficiently complementing the delivered action plan.

Within the aforementioned context, this paper aims to provide a comprehensive overview of major risks, as identified and assessed by leading experts following a structured approach, that can potentially hinder or delay the development and uptake of promising and novel maritime transport solutions capable of delivering further efficiencies to the system, thus recommend a number of appropriate mitigation strategies and measures. To this end, the rest of the paper is structured as follows: a brief overview of the project's work plan for delivering the vision for the European transport system in 2030 is being provided first; the methodology and consecutive steps followed for defining and selecting the most promising solutions in the maritime transport sector and assessing implementation risks are being described in section 2; a description of the risks rated as most severe is being provided in section 3 along with possible mitigation measures that have been

identified; section 4 concludes the paper providing a critical overview of all 58 risks identified (including both severe, moderate and insignificant ones) highlighting key points that need to be taken into consideration for moving towards a more efficient and sustainable European maritime transport system in 2030.

1.2 *Mobility4EU project overview*

Mobility4EU is a Coordination and Support Action funded under the Horizon 2020 programme of the European Commission from January 2016 to December 2018. As mentioned before, its overall objective is to deliver a vision for the European transport system in 2030 and an action plan, including a roadmap, for implementing that vision. To this end, recommendations for tangible measures in research, innovation and implementation targeting various stakeholder groups are being provided.

For meeting the project's overall objective, a number of societal challenges expected to influence future transport demand and supply were identified and assessed. More specifically, at the first phase of the project, 9 trends likely to shape the European transport system in 2030 were identified and were used as the starting point for devising the Mobility4EU context map (Mobility4EU, 2016). As a next step, with the support of European experts specializing in all fields of transport and covering both passenger and freight transport, a portfolio of 93 promising and innovative transport solutions addressing the identified user needs was formulated. The latter included solutions in concept or at research stage, but also incorporated recently implemented ones that need to be further supported for advancing their respective technologies or products and achieving wider implementation and deployment (Mobility4EU, 2018a).

Building upon the trends identified and the portfolio of innovative transport solutions formulated, a series of scenarios for the future of the transport system in Europe were developed utilizing the Multi-Actor Multi-Criteria Analysis (MAMCA) methodology (Macharis, 2007). In addition, the aforementioned results were also used as the basis for identifying and assessing implementation risks and barriers using the extended Failure Modes and Effects Analysis (FMEA) methodology, which was properly adjusted for meeting the needs of the Mobility4EU project. A large group of experts representing all key stakeholders, sourced from the project's consortium and associated partners, were mobilized and supported the aforementioned process ensuring in that way the validity of the results, which are being presented for the maritime transport sector within the following sections.

The aforementioned consecutive steps comprising the project's work plan are clearly illustrated in the following figure (Figure 2).

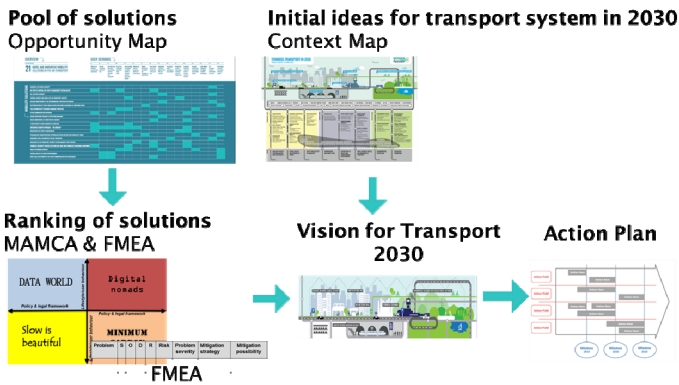


Figure 2. Steps followed in Mobility4EU for delivering the vision and action plan for the European transport system in 2030 (Mobility4EU, 2018a).

2 RISK ASSESSMENT ANALYSIS FOR FUTURE TRANSPORT TRENDS AND INNOVATIVE SOLUTIONS

2.1 The extended FMEA methodology

The classical FMEA procedure is a tool that has been adapted in many different ways and for various purposes. It can contribute to improved designs for different products and processes, resulting in higher reliability, better quality, increased safety, enhanced customer satisfaction and reduced costs.

In the Mobility4EU project, the extended FMEA methodology, as developed in the ADVISORS project (Bekiaris and Stevens, 2005), was used for defining and assessing the risks of future transport trends and innovative solutions, since it proved to be fitting best the project's needs. It is based on the classical FMEA, which includes indicators of hazard consequence severity, occurrence probability, detectability and recoverability, but extends it by covering not only technical but also behavioural, legal and organizational – related risks. Risks are first identified and the level of risk is then assessed considering a number of characteristics for each risk type (i.e. technical, behavioural, legal and organisational). The significance of a risk overall depends on its consequences and the probability of its occurrence, but also on how easily it can be detected.

The overall process to be followed based on to the extended FMEA methodology is being presented in Figure 3. As mentioned before, a number of risk types are being combined and incompatibilities or conflicts between different issues that may exist are being considered. Depending on which stakeholders are assessing and validating the risks, some risks may be unfavorable to all, whilst others may be inconvenient for specific stakeholders but benefit oth-

ers. To this end, all stakeholder groups should be represented and get engaged in this process.

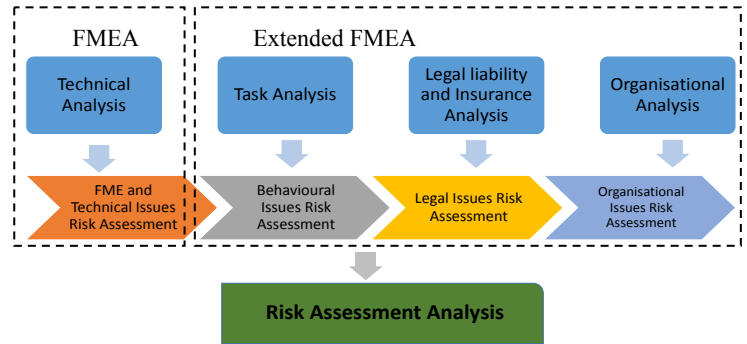


Figure 3: The extended FMEA (Bekiaris & Stevens, 2005).

2.2 Application of the extended FMEA methodology in Mobility4EU

As mentioned above, a risk assessment consists of the identification and analysis of different risks (i.e. the identification of potential hazards and some estimation of their magnitude) and an evaluation of their tolerability in the relevant context. The steps that were followed, within the extended FMEA methodology for assessing possible implementation risks of the promising and innovative transport solutions that were selected in Mobility4EU are depicted in Figure 4 and are briefly described within the following sub-sections.

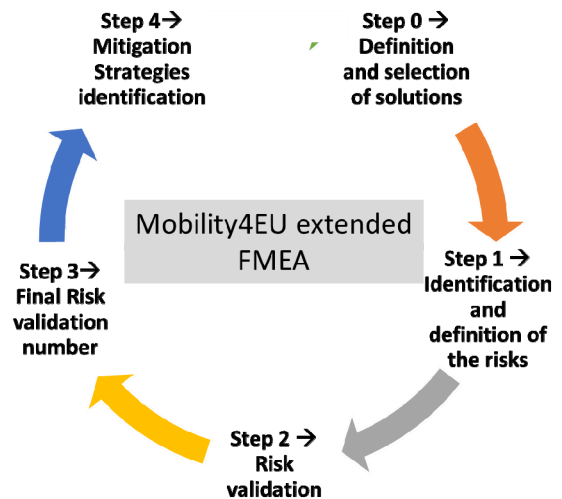


Figure 4: Steps of FMEA methodology, as implemented in Mobility4EU (Mobility4EU, 2018b).

2.2.1 Step 0 - Definition and selection of solutions

For the application of the extended FMEA methodology, the 93 promising and innovative transport solutions that were identified at the first stage of the project had to be narrowed down in order to come-up with a feasible set of solutions to be assessed for each transport mode. To this end, experts were called to identify and rank the most critical solutions

and the final sets were developed for each mode. For the maritime transport sector, the following 7 solutions were included in the final set:

1. *Alternative fuels*: With stricter emission limits on shipping being put forward (e.g. Emission Control Areas), the use of alternative fuels such as liquefied natural gas (LNG), bio-mass, methanol, etc. is being widely investigated since the relative reductions of air emissions are expected to be substantial. Such an operational environment highlights also the need for fuel-flexible vessels (i.e. engines and subsystems) that could effectively adapt to competitive market prices of certain fuels, thus meet current and planned (stricter) environmental regulations.
2. *Autonomous vessels for freight and passengers*: As vehicle automation progresses and considering the rather clear infrastructure of maritime transport compared to road, technical competences are being increasingly and rapidly transferred to vessels highlighting the latter as an optimal application field for automation. Systems' automation (e.g. navigation and route optimization), the availability of smart sensors and global networks for data transfer from ship to shore will promote remote-controlled and semi or fully autonomous vessels. The deployment of autonomous vessels is expected to significantly disrupt the shipping industry thus impose a significant impact on existing job profiles (e.g. remote control hubs operators) and the relevant skills needed.
3. *Blue modal shift - bringing transport to the waterways (in the urban environment)*: With road transport often reaching its maximum capacity and creating high levels of congestion, a modal shift towards waterborne transport in the urban environment (i.e. inland waterways or waterborne commuter solutions) can lead to the realization of significant economic and environmental benefits. For increasing the current relative low share of such modes, the relevant infrastructure needs to be modernized and be specialized in each context in terms of load (e.g. passengers and cars) and connectivity with land modes. Passenger, car or bike transfer on rivers in urban areas can for example significantly shorten urban routes compared to bridges. As a next step, and in line with solution 2, the platooning of vessels or ferries can be realized providing additional benefits and increasing the modes' attractiveness.
4. *Energy efficient and low emission ship*: Energy efficiency and increased environmental performance of ships can be reached through the deployment of various solutions including enhanced hydrodynamic performance, more efficient propulsion systems, reduced demand of on-board systems (e.g. lighting, working devices), employment of scrubbers, ballast water systems, etc.

5. *Hybrid and electrified ferries and vessels in ports*: Hybridization and electrification of ferries and of vessels in ports is already ongoing (e.g. 'Ampere' electric ferry in Norway, 'Copenhagen' and 'Berlin' hybrid electric Scandinavian ferries, etc.). However, further advancements are needed in order to enable longer electrified routes and higher loads. Ferries in particular operate on a fixed schedule with short docking times and would significantly benefit from wireless, inductive power transfer technologies.
6. *Multi-skilling and competence-based port labour training schemes*: Digitization at ports, a new working environment resulting from the introduction and development of global terminal operators as well as changing patterns of labour supply have led to the demand of new and/or combined skills, with training programs shifting from 'job analysis' to the identification of competences required for a given function.
7. *Smart connected vessels and ports*: Key ICT innovations in systems and software will affect almost all aspects of maritime transport processes. On-board increased communication between systems leading to vessels becoming 'system of systems' (i.e. smart connected vessels) together with critical infrastructure such as port and logistics sites will enable more efficient cargo handling processes, route planning etc. Technologies of augmented and virtual reality present also an increased potential application for managing for example vessel (bridge) operations, improving port and logistics infrastructure and operations, planning new terminals or assessing existing ones as well as for training purposes.

2.2.2 Step 1 - Identification and definition of the risks

For each of the aforementioned solutions, technical, legal, organizational and behavioural risks had to be identified and the following characteristics of the latter had to be defined:

- Risk mode → what is the possible risk.
- Risk effect → what is the effect if this risk occurs.
- Risk cause → what might trigger this risk to occur.
- Risk detection & recognition → how this risk is detected when it occurs.

2.2.3 Step 2 – Risk validation

For validating the identified risks, their severity, occurrence probability, detectability and recoverability were assessed using a 1-10 scale, where 10 represents an extremely severe, with high occurrence probability, improbable and non-recoverable risk. Within this process, different aspects were taken into consideration based on the risk type.

Risk Severity (S)

- *Technical risks analysis*: Technical risks consist of technical (hardware and software) failures of the solutions of Step 0 or risks that are related to their technical maturity.
- *Behavioural risks analysis*: Behavioural risks are associated with the behavior of users and organizations that have a negative impact on the society and on the selected solution (e.g. human error issues).
- *Legal risks analysis*: Legal risks include significant legal issues that are likely to affect solution implementation and deployment (e.g. change to existing law required for solution implementation, significant legal cost for deployment, large potential liabilities, etc.).
- *Organizational risks analysis*: Lack of communication and reporting structures between actors can create a number of organizational risks that should be taken into consideration (e.g. accounting failures, frauds, internal control breaches, governance failures, etc.).

Risk Occurrence Probability (O)

Risk occurrence probability is the probability that all the risk causes related to the risk modes can occur. This is often a qualitative index especially when new technologies are concerned because of limited reliability data often available.

Risk Detectability (D)

Risk detectability is the probability to detect the occurrence of a risk mode at an early stage. Detection of a developing risk is an important aspect in risk management, as early detection can facilitate the efficient application of mitigation strategies. With regard to technical, and to some extent behavioural risks, detection can be supported by sensors and data processing. For legal and organizational risks, surveys, monitoring and feedback are important tools.

Risk Recoverability (R)

Risk recoverability is an efficacy index of the possible recovery action to be performed following risk management procedures. It estimates the ability of a solution to tolerate the risk.

2.2.4 Step 3- Final risk validation number

Among the different risks identified, classified and validated, an overall relative indication of their significance is very useful, and to this end a risk number (RN) can be calculated within the extended FMEA, using the following formula:

$$\text{Risk Number} = S * O * \left[\frac{D + R}{2} \right]$$

This calculation is applied to each category of risks with the respective results ranging from 0-1000

depending on the validity of each risk, as indicated in the following table (Table 1).

Table 1 : Risk evaluation based on the overall risk number (Mobility4EU, 2018b)

Overall risk number	Overall severity	Mitigation possibility
513-1000	Extremely severe	Very high
217-512	Severe	High
65-216	Moderate	Medium
9-64	Slight	Low
1-8	Insignificant	Improbable

Normally, organizations select a pre-defined range for the RN (i.e. the 513-1000 range is often selected since it includes the most severe risks but wider ranges can also be considered) and mitigation strategies are being implemented for the risks included in the selected range. Through this process, the use of available resources can be optimized and costs can be minimized.

Such a range (i.e. 513-1000) was also used in Mobility4EU, and the 12 most severe risks included for the 7 ‘critical’ innovative maritime transport solutions reported in Step 0, are being described within the following section along with the proposed mitigation strategies / measures.

3 ASSESSMENT OF SEVERE RISKS FOR THE IMPLEMENTATION OF INNOVATIVE MARITIME TRANSPORT SOLUTIONS

For each of the 7 critical innovative maritime transport solutions identified in Step 0, the most severe implementation risks are being described below along with a set of proposed mitigation strategies / measures.

Solution: Alternative fuels

Risk 1 (Organizational): The impact of the global financial crisis, investment uncertainty on both the supply and demand side for alternative fuels, and shipping economic cycles, have significantly hindered or have not enabled maritime transport stakeholders (e.g. ship-owners, port authorities, etc.) to have the required capital for investing on alternative fuel technologies. As a result, the share of alternatively fuelled vessels, port equipment, vehicles, etc. in existing fleets is still quite small and their relative increase in the near future is expected to be very slow.

Mitigation strategy: This risk cannot be easily mitigated as investment decisions depend on a variety of different factors (e.g. economic environment, business dynamics, etc.). However, low interest rates may provide the necessary capital for investment.

Risk 2 (Organizational): The high investment uncertainty characterizing the alternative fuel market in shipping has led to inadequate supply or demand as well as to the absence of market leaders that could potentially drive their development and thus their faster and larger penetration in the marine fuel market.

Mitigation strategy: The introduction of more strict environmental regulations in shipping and in ports, as well as the formulation of the necessary legal framework for the bunkering and use of alternative fuels, will support the development of the required supply and demand and consequently the rise of the relevant market. The financial support provided by relevant programs (e.g. Connecting Europe Facility) for the development of the required infrastructure is also very important for mitigating this risk.

Solution: Hybrid and electrified ferries and vessels in ports

Risk 3 (Organizational): The severe impact of the global financial crisis in shipping and the high investment uncertainty characterizing the sector have contributed towards ship-owners lacking the capital required for introducing hybrid and electrified vessels in their fleets. As a result, the relative share of such vessels is still very low and is expected to not increase considerably in the following years.

Mitigation strategy: This risk cannot be easily mitigated as investment decisions depend on a variety of different factors (e.g. economic environment, business dynamics, etc.). However, low interest rates may provide the necessary capital for investing on hybrid and electrified vessels.

Solution: Autonomous vessels for freight and passengers

Risk 4 (Legal): For introducing autonomous vessels in the market, all relevant legal aspects related to their operation need to be carefully taken into consideration and tackled. This will require a long consultation process, where the engagement of all relevant stakeholders needs to be ensured, thus the formal approval processes by relevant bodies is often slow. At regional level, the relevant processes may be more complex since for example at European level national policies of Member States will need to be aligned. The delay in formulating the appropriate legal framework (i.e. at European level, national level, etc.) governing the operation of autonomous vessels at sea and in ports would lead to a longer, than expected, time horizon for autonomous vessels to enter into service.

Mitigation strategy: This risk can be mitigated by allocating targeted research funds to investigate the regulatory and legal frameworks / amendments (including liability regimes) required for the successful operation of autonomous vessels in the envi-

ronment of early adopters (e.g. inland waterway transport) as well as that of followers. Industry pressures (especially of global players) and political support may place such an issue high in the political agenda of the EU and Member States and accelerate the required policy reform / introduction processes.

Risk 5 (Legal): Extended time periods are also required for specifying required revisions and additions in international shipping conventions so that the operation of autonomous vessels can be facilitated. Such a process will also require long consultations with all relevant stakeholders while the formal approval process by the responsible regulating authorities may also be slow.

Mitigation strategy: This risk can be mitigated by allocating targeted research funds to identify possible amendments required to international conventions for the safe and efficient operation of autonomous vessels in intercontinental shipping. The successful operation of such vessels in a smaller scale and other environments (e.g. first adopters) as well as the introduction of all necessary regulatory and legal requirements at EU and Member State level may facilitate and accelerate such a process, which may be further assisted by high industry demand and increased political support.

Solution: Energy efficient and low emission ships

Risk 6 (Organizational): The severe impact of the global financial crisis, coupled with shipping economic cycles, has contributed towards a lack of capital of ship-owners to invest in measures for enhancing the energy and environmental performance of their vessels. Furthermore, the absence of more strict environmental regulations in shipping has resulted in a low demand of ship-owners for the implementation of such measures / technologies.

Mitigation strategy: This risk cannot be easily mitigated as investment decisions depend on a variety of different factors (e.g. economic environment, business dynamics, etc.). However, low interest rates may provide the necessary capital for investment while stricter environmental regulations in shipping may support a growth in demand for such measures / technologies.

Risk 7 (Organizational): The wider benefits that alternatively fuelled vessels may provide (i.e. energy, environmental, cost savings, etc.), the conformity of the latter with more strict shipping environmental regulations that may be enforced in the near future as well as the lower investment risk that such vessels present (on the long-term), may overrule the potential benefits to be achieved by a single or set (if appropriate) of energy and environmental efficiency improvement measures / technologies. As a result, the interest of ship-owners to invest on such measures can be low.

Mitigation strategy: This risk cannot be easily mitigated and depends on the development of the relevant market (i.e. for alternative fuels). However, the lower investment required for the implementation of such measures / technologies compared to alternatively fuelled vessels, vis-a-vis the environmental restrictions that are currently in force (more strict limits are planned to be enforced in the future) may withhold investments interests being transferred to alternatively-fuelled vessels.

Solution: Blue modal shift – bringing transport to the waterways (in the urban environment)

Risk 8 (Organizational): Physical urban network limitations (e.g. inability to serve large urban areas), the need to be combined with other modes of transport for completing an urban trip, and the often low connectivity between the different modes (e.g. lack of intermodal interchanges or services - frequencies not well aligned, etc.) can lead to significant increases in travel time and consequently to a low demand for waterborne and inland waterway transport services in the urban environment decreasing in that way their modal share.

Mitigation strategy: This risk may be mitigated by modernizing current infrastructure (e.g. new vessels), ensuring reliable services (i.e. adherence to timetables) and improving connectivity with other transport modes time, location and fare-wise (i.e. integrated planning, intermodal interchanges, integrated fare systems, etc.).

Risk 9 (Organizational): High fares for passengers and additional handling costs for freight (although operational costs may be lower depending on capacity utilization) together with the combination of modes required for reaching final destinations, can lead to increases in travel costs, lowering as in the previous case the demand for waterborne and inland waterway transport services in the urban environment and consequently decreasing their modal share.

Mitigation strategy: This risk may be mitigated by ensuring high capacity utilization rates with regard to both passengers (i.e. appropriate service frequency) and freight (i.e. targeting low-value goods with higher lead times).

Risk 10 (Organizational): Services of low frequency, significant delays experienced and run-down vessels (i.e. not properly maintained) may lead towards low service quality, reliability and passenger comfort that would again result in low demand for waterborne and inland waterway transport modes in the urban environment and in decrease of their modal share.

Mitigation strategy: This risk can be mitigated by targeted infrastructure investments (e.g. new vessels, infrastructure in ports, ferry stations, etc.) and

careful and integrated planning (e.g. service frequency, fare policy, efficient connections with other transport modes, etc.).

Solution: Smart connected vessels and automated ports

Risk 11 (Legal): The implementation of smart connected vessels and port automation will require the collection of data via on-board / off-board monitors. Thus, it would bring in the scenery cloud computing, wireless communication technologies, Internet of Things and Big Data analytics; all these technologies integrated in smart connected vessels will trigger legal issues such as personal data sensitivity issues, cyber security, etc.

Mitigation strategy: The risk can be avoided by enforcing strict compliance with European Union and national legislations.

Risk 12 (Legal): Smart unmanned connected vessels may perform specific actions (via remote control). At the moment there is an absence of relevant legislative actions and problem of performance of legal obligations can thus be created.

Mitigation strategy: The risk can be only avoided by the necessary legislative actions being introduced by the European Union and Member States.

4 CONCLUSIONS

Within the context of the Mobility4EU project, a thorough risk analysis was conducted with regard to the implementation of 45 critical innovative transport solutions, out of total 93 that were identified, considering all modes of transport and covering both passengers and freight. The focus of this paper was confined on the maritime transport sector and for the 7 most critical solutions, as identified by relevant experts, the 12 most severe implementation risks were identified and presented. The majority included organizational risks (8), with several of them sharing a common ground that mainly refers to the heavy impact of the financial crisis on the shipping sector coupled with an investment uncertainty that the latter provides, which however differs based on the specific market that is being addressed (e.g. marine fuel market, shipbuilding, ship retrofitting, etc.). All remaining risks are legal ones highlighting the absence of appropriate regulatory frameworks that need to be established for tackling all relevant issues coupled with the introduction of new and innovative technologies that the respective solutions entail. No technical and behavioral risks were assessed by the relevant experts as severe.

Overall, a set of 58 risks (including severe, moderate and insignificant ones) were assessed. From these, 19 were categorized as organizational 19 as technical, 16 as legal and only 4 as behavioural (Figure 5).

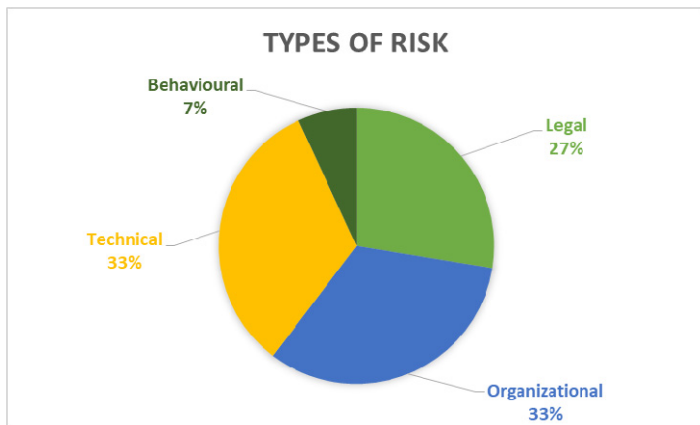


Figure 5: Classification of total implementation risks for innovative maritime transport solutions (Mobility4EU, 2018b)

It is clear from Figure 5 that organizational, technical and legal risks were equally represented in the assessment that was performed while behavioral ones prove to be lacking content. A possible explanation for this could be that the maritime transport sector is currently subject to increased penetration of new and innovative technologies which, as also mentioned before, for becoming operational more important barriers related to technical specifications, organizational issues and policies that need to be in place need to be overcome compared to the ones related with the behavior of the stakeholders involved. This does not imply however that such risks are not important, but before addressing them, experts need first to be sure that technical, organizational and legal challenges can be successfully overcome.

As mentioned before behavioral but also technical risks were not ranked as severe. With regard to the latter extensive research and pilot-testing may ensure that all technical inefficiencies can be detected as different development levels raising the technology readiness level of the solution under consideration. On the other hand, experts expressed a clear worry on the organizational part of the solutions, paying also increased attention on the relevant legal framework that should be formed or revised for efficiently tackling all relevant aspects. Changing business as it integrates high risks which when coupled with an uncertain economic and dynamic business environment as shipping is, further complicates and hardens investment decisions. This was clearly expressed by experts with regard to many of the solutions under consideration highlighting that the high costs for new vessels, infrastructure and equipment cannot be easily borne and different funding structures and initiatives may greatly contribute towards realizing a business shift towards for example more clear fuels and technologies.

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