Deliverable D4.4
Business Risk Analysis of Virtual Coupling

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Table of Contents

List of tables

List of figures

Executive summary

This document constitutes MOVINGRAIL Deliverable D4.4 ‘Business Risk Analysis of Virtual Coupling’ in the framework of TD2.8 of IP2 according to the Shift2Rail Multi-Annual Action plan (MAAP).

The implementation of new technologies in the railways depends not only on their technical feasibility, but also on their commercial, regulatory, and political viability. Building on previous deliverables that focused on the cost-benefit analyses and roadmaps for implementation, this deliverable focuses on the business risks associated with the implementation of Virtual Coupling in the different sectors of European railways. The main aim of this study was to identify potential risks for implementation, and assess their criticality in the form of barriers to the deployment of Virtual Coupling.

To do so, a four-stage iterative process was adopted using inputs from relevant stakeholders from industry, academia, and regulators. An initial list of business risks was compiled, clustered into nine themes, and transformed into an online survey. Respondents were asked to rank each risk according to its probability and impact. Respondents were also invited to suggest additional risks which were subsequently adopted. The third stage involved a workshop with key stakeholders to validate and further comment on the risks and their ratings, culminating in analysis and summary of the risk register.

Using the results from eleven respondents, who self-identified as having limited, practitioner, or expert knowledge of the field, this deliverable analyses the criticality of each risk. Data was analysed in a number of ways, looking not only at overall average scores but also at measuring how each expertise group assessed each risk. Given the potential for some risks to completely stall implementation, scores for impact were analysed separately.

A number of conclusions could be drawn from the results from the surveys and workshop. Overall, the major criticality for the implementation of Virtual Coupling refers to operators not adopting the technology due to business or safety concerns. In relating to business concerns, respondents highlighted the risks of Virtual Coupling not delivering sufficient benefits compared to the costs, and also of only working in specific route / service configurations. In terms of safety concerns, this review identified that if the risk of rear end collision (following a rapid deceleration of the leading train) is not fully mitigated, there is unlikely to be a business or regulatory appetite to implement this technology.

Abbreviations and acronyms

Abbreviation/Acronym	Description
ATO	Automatic Train Operation
ATP	Automatic Train Protection
CBTC	Communications-Based Train Control
CCS	Command, Control, and Signalling
CSM-RA	Common Safety Method for Risk Evaluation and Assessment
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
EU	European Union
EUAR	European Union Agency for Railways
HSR	High-Speed Rail
ICT	Internet Communication Technology
IPR	Intellectual Property Rights
MB	Moving Block
MOVINGRAIL	MOving block and VIrtual coupling New Generations of RAIL signalling
R&D	Research and Development
SD	Standard Deviation
VC	Virtual Coupling
WP2	Work Package 2

1. Introduction

This report considers the business risks associated with the potential introduction of the technology of Virtual Coupling on the European railway market.

Building on the work conducted to date where the market potential, cost-effectiveness, and roadmap of Virtual Coupling were analysed in deliverables D4.1, D4.2 and D4.3, this deliverable turns attention to the business side of the technology. When the technical capability for running trains closer together is achieved, there remain potential hurdles to implementation in an industry that has regulatory and structural barriers to change.

With that, the study presented in this deliverable engaged with various stakeholders of the railway sector and investigated the business risks that could potentially prevent the implementation of the technology of Virtual Coupling. Although technical challenges have been addressed elsewhere, this work identified that there are considerable linkages between the technical risks and the willingness of the business community to embrace the new technology.

2. Background

2.1. General definitions

The MOVINGRAIL project uses the definition of Virtual Coupling as a further step from Moving Block principles such as ETCS Level 3 and CBTC, where train separation can be shorter than the absolute braking distances. The concept comprises railway operations where block segregation and trackside equipment are not necessary anymore. The supervision of train integrity and the maintenance of safe distances between trains is done on-board trains. In the Virtual Coupling level of technological maturity, trains are able to form a platoon where they move synchronously at a distance that is less than the braking curve of the following trains, which has the potential to increase the capacity of the line.

The idea behind Virtual Coupling has been in discussion for a few decades, when the developments in automation opened up the possibility to run vehicles closer together. While the implementation of platooning of self-driving vehicles seems to be relatively close in the road industry, the case in the railway environment is less certain. Not only are there are additional technical challenges to be addressed due to the specific context of rail operations, but also there are specific business risks that may prevent Virtual Coupling from being deployed.

Railway operations involve a number of stakeholders in a complicated structure where regulators, suppliers, operators, infrastructure managers, and passengers are often identified as having conflicting interests.

3. Methodology

3.1. Definition of business risks

The study in this deliverable was designed to apply expert knowledge from industry and academia to identify, analyse, and rank the various business risks that may arise in the deployment of virtual coupling. It consisted of four main stages, see Figure 1.

Stage One – Creation of list of business risks

The first step consisted in establishing an initial list of business risks. The task team defined a range of topics that relate to the various elements of the railway sector as a business, and populated these with risks under generic themes. There is no particular value attached to each of the generic themes, other than that they enabled the results to be analysed in a more granular form. The initial set of risks, created by the authors were enhanced and refined through a series of iterations between the project members which resulted in an addition of four risks to the original list (risks 4.7 to 4.10).

Stage Two – Risk ranking and initial validation of the list

An on line survey was conducted to establish their criticality and to give respondents the ability to add risks they believed to be missing. In this stage, three risks were added (risks 6.4, 6.5, and 6.6) This stage is described in more detail in section 3.2.

Stage Three – Workshop of consortium members and stakeholders

On online workshop was held to share the findings with a wider field of stakeholders and to give an opportunity to add additional risks. All the risks were endorsed (i.e. none were challenged) apart from the wording used, and three additional risks were added during the course of the workshop (risks 7.8, 7.9, and 7.10), which explain the different number of risks evaluated by respondents at different dates.

The consolidated list of risks is shown on Table 1.

Stage Four - Analysis of the results

In analysing the results and drawing conclusions, task members engaged with Tasks 4.2 and 4.3 and project X2Rail-3 to ensure cohesion between business risks, operational definitions, cost-benefit analysis, and roadmap for implementation.

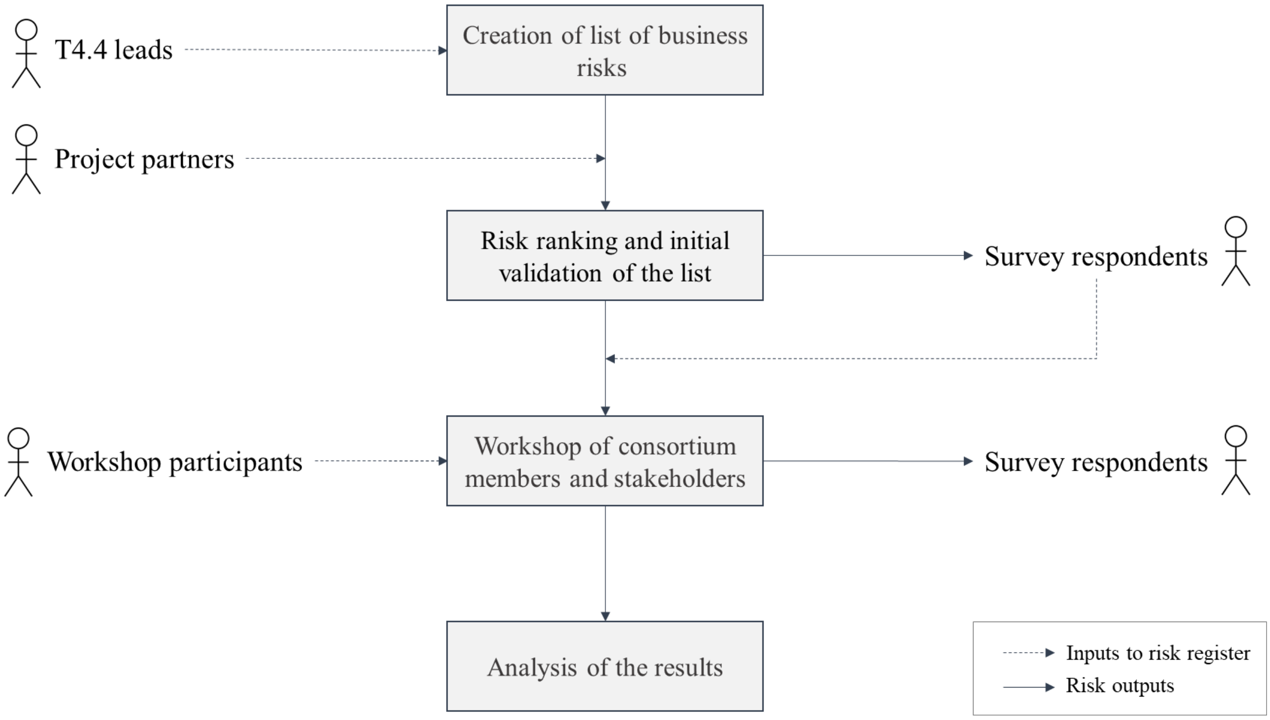

Figure 1. The four-stage process of the study

Table 1. List of business risks identified in this task.

RISK	
Standards	
1.1	Emergence of different proprietary solutions
1.2	Excessive time elapses from proof of concept to defining actual specifications
1.3	Development of a number of black box solutions
1.4	Failure to Integrate into EU/EUAR plan for standards
1.5	Constantly changing/evolving definition of solution
1.6	Incompatibility with ETCS / Class B Systems
Supply side	
2.1	Proof of concept works, but no suppliers want to invest in it
2.2	Different suppliers develop slightly different solutions
2.3	Supply industry opposes the overall introduction of Virtual Coupling
2.4	Issues emerge with ownership of IPR for solutions
2.5	Different suppliers develop solutions compatible only with their existing products/systems
Operations side	
3.1	No take up from operators due to business/safety concerns
3.2	Failure to develop a common concepts of operations and Rule Book
3.3	Emergence of disagreement over role of train operators and infrastructure managers in deployment
3.4	No take up from operators due to competition (don’t want to be coupled to a competitive train operator)
3.5	Operators want so many different/incompatible functions that the system is too complex and/or expensive to develop
3.6	Operators unable to derive tangible commercial or customer benefits from the technology
Technical	
4.1	The system does not deliver the required outputs

4.2	Level of reliability and availability not sufficient
4.3	Lack of availability of spectrum for Communications
4.4	Solution exposes system to greater Cyber Security risks
4.5	Failure to develop a solution for handling of grade crossings
4.6	VC will require a change to point switching technology
4.7	The added complexity of cooperative train control technologies needed to maximise benefits of Virtual Coupling creates unexpected system risks
4.8	Need to upgrade existing on-board systems and adaptation of logical ICT systems
4.9	Trains cannot run closer together than ETCS L3
4.10	Trains can run closer on plain line but not in junction/station/complex layouts - thus limiting the benefit
4.11	Repeated failures during operation
4.12	Degraded mode operation worse than current
Regulatory	
5.1	Uncertainty about who will 'sign off' the system
5.2	Interaction between national safety authority and EURA jurisdiction causes delay in process of approval
5.3	Non fulfilment of CSM-RA
5.4	UK/EU Brexit Issues restrict British contribution to project/solutions
5.5	System shown to work but not supported by Commission
Transition/implementation issues	
6.1	Most promising routes for upgrade have most modern signalling
6.2	Incompatibility with existing systems at interfaces or if used as an overlay system
6.3	Migration to ETCS Level 3 with Moving Block never delivered
6.4	Migration to ETCS Level 3 with Moving Block may take a very long time
6.5	Uncertainty about track, train, route systems and the migration sequence
Business case	
7.1	Costs exceed the benefits
7.2	Costs understood, benefits less clear and in the future
7.3	Unable to define the Units of output at which benefits exceed the costs
7.4	Uncertainty about lifetime costs (maintenance and recovery)
7.5	Uncertainty about compatibility with next generation of CCS
7.6	Uncertainty about what risks (schedule, technical and cost) to build in to project evaluations
7.7	Insurers become reluctant to carry risks of solutions
7.8	Elapsed time between now and implementation may change business cases
7.9	Passengers may not adjust to the different operations
7.10	Business case impossible to forecast before implementation
Public acceptance	
8.1	Media/public suspicious of trains that cannot stop in the gap to the next train
Safety	
9.1	Accident during testing undermines confidence
9.2	Accident during live operation undermines confidence
9.3	Near misses during testing
9.4	Near misses during operations
9.5	Repeated failures not leading to incidents

3.2. Business risks survey

Following consolidation, the business risks were transferred into an online survey to be analysed

and ranked by key expert stakeholders. The survey was designed as an online questionnaire, kept open for completion between 28th April 2020 and 22nd May 2020. Invitations were sent initially to a contact list from key stakeholders that demonstrated an interest in the project during the preparation for the MOVINGRAIL WP2 workshop in May 2019. The consortium sought to engage with a wide array of practitioners whose work and/or expertise relate to the concept of Virtual Coupling, in order to establish a balanced view of business risks that encompasses the multiple perspectives involved. Representatives from the following stakeholders were invited to take part in the survey:

- Railway operators
- Railway safety
- Regulatory bodies
- Signalling organisations
- EU Agency for Railways.

The survey was fully anonymised, where only the respondent's country was logged to assess representation together with a screening question, allowing respondents to self-identify as having limited, practitioner, or expert knowledge in the topics relating to Virtual Coupling. Participants were also able to add additional risks to the list if they identified any missing.

Each respondent was asked to score the probability and the impact of each business risk to the implementation of Virtual Coupling in European railways. Using a scale between 1 and 10, participants were briefed with the following two guidelines for scoring risks:

- The lowest **probability** is 1 (most unlikely to occur at all) and the highest is 10 (virtually inevitable)
- On **impact**, 1 is of little or temporary consequence while 10 is devastating to the project/technology

As described in the previous section, the survey consisted of an open-ended iterative process where new risks could be added to the list. Therefore, some of the risks were scored by more respondents than others.

The scoring of risks was based on averages in order to reflect the different number of responses. The resulting score (S) for each risk consisted of the average of the *n* respondents' products of probability (P_i) and impact (I_i) for that risk:

$$S = \frac{1}{n}\sum_{i=1}^{n}\left[P_{r_i} \cdot I_{r_i}\right].$$

3.3. Business risks workshop

Originally, a workshop was scheduled at the University of Birmingham's Europe Hub in Brussels to bring together specialists and practitioners to review survey results and further consolidate the assessment of business risks from a qualitative perspective. However, due to the travel restrictions imposed by Covid-19, the workshop was moved to a virtual platform.

With the changes, the University of Birmingham hosted an online workshop on the 6th May. Invitations were sent three weeks in advance to the same list of the survey, comprising 56 contacts. Of those, 23 participated in the workshop, representing 13 organisations based in seven different countries.

The workshop combined discussions over a Roadmap for Virtual Coupling implementation (Task 4.3) and Business Risk Analysis (Task 4.4). MOVINGRAIL partners presented interim results to the audience, opening the virtual floor for discussion afterwards. In relation to Business Risk Analysis, participants were asked to assess interim criticality rankings based on the scores of each risk. There was no disagreement over the order of criticality found from the survey at that point.

Participants were then consulted on the risks elicited. There was a general consensus regarding the comprehensiveness of the list, with most of the focus turned towards description and wording of risks. Participants agreed on extending the deadline for survey submission, which enabled one additional response.

4. Analysis of results

4.1. Participant overview

The survey was completed by 11 respondents from five different countries: United Kingdom, Netherlands, Sweden, Denmark, Belgium, and Germany. Of these, three self-classified as having limited knowledge about signalling systems, two classified themselves as practitioners, and five presented their views as experts in the field.

Six respondents completed the survey from the first invitation sent, while the other four completed the survey following the workshop. These four respondents all completed the online survey on the 12th May, most likely as a result of the post-workshop e-mail communication sent to the project contact list. A final respondent completed the survey after the project meeting in June where it was agreed to send the invitations once again.

4.2. Overall results

Each respondent's questionnaire was first treated separately. For each risk assessed by each respondent, we calculated a respondent score as the product of the probability and impact scores. Subsequently, we calculated the overall score for each risk as the average between all responses. The maximum possible score is therefore 100, although the range of risk rankings produced by the averaging process is from 69.8 to 14.0

The 55 risks were ordered by their overall scores, and compiled in their respective themes. Of those, the ten highest scores are presented in Table 2. The ranking does not include single entries because they do not reflect a balanced perspective that includes different levels of expertise and/or different professional interactions with the concept. The full list of ordered risks can be found in Appendix A.

Results indicate that most of the highest scoring risks are on the technical (4.8, 4.7, 4.10), business (7.1, 7.8), and supply side (2.1, 2.2).

However, the highest scoring risk, by a considerable margin, is risk 3.1, which relates to operators refraining from adopting Virtual Coupling due to business and/or safety concerns.

Such risk relates closely to a few others in the table, highlighting that the concerns around the technology emerge from the cost-benefit of the investment needed.

Risk 4.10 being highly ranked points out that the industry requires substantial proof of considerable operational improvements in comparison to moving block signalling (ETCS L3). In particular, one participant of the workshop declined to fill in the survey stating that 'try hard as they have, they could not see any benefit arising from Virtual Coupling'. On the other hand, there was a consensus amongst respondents that the technology could technically be achieved at some point. The question becomes a matter of 'if' Virtual Coupling would be deployed rather than if it could be made to work.

Table 2. Highest scoring risks

RISK		Overall score
3.1	No take up from operators due to business/safety concerns	69.8
6.4	Migration to ETCS Level 3 with Moving Block may take a very long time	58.6
7.1	Costs exceed the benefits	57.6
4.8	Need to upgrade existing on-board systems and adaptation of logical ICT systems	52.3
7.8	Elapsed time between now and implementation may change business cases	51.4
2.2	Different suppliers develop slightly different solutions	48.1
4.7	The added complexity of cooperative train control technologies needed to maximise benefits of Virtual Coupling creates unexpected system risks	48.0
2.1	Proof of concept works, but no suppliers want to invest in it	47.5
1.2	Excessive time elapses from proof of concept to defining actual specifications	46.8
4.10	Trains can run closer on plain line but not in junction/station/complex layouts - thus limiting the benefit	46.6

In contrast, some risks were considered by respondents to be low, as shown on Table 3. For instance, respondents do not foresee passengers' reluctance to use the new technology as a barrier to implementation. Moreover, the other four of the lowest ranked risks relate to confidence during sub-optimal operations. One interpretation of these assessments may reflect the underlying belief that the implementation of Virtual Coupling can only take place after the technical assurance of the technology (which itself may take some considerable time).

Table 3. Lowest scoring risks

RISK		Overall score
7.9	Passengers may not adjust to the different operations	14.0
4.11	Repeated failures during operation	20.5
4.12	Degraded mode operation worse than current	21.7
9.4	Near misses during operations	23.3
9.2	Accident during live operation undermines confidence	23.9

4.3. Further analysis of results

On top of the scoring systems used to assess the criticality of each business risk, we also investigated the sensitivities attached to each response. Given that the scoring system is based on the average score between respondents, it is appropriate to examine the range of scores and the influence of expertise on perceived criticality. The former (looking at the standard deviations of each ranking) highlights whether a certain score is consensual or a middle point between extreme views, and the latter (presenting the results by level of expertise) sheds light on the perception of risk that people with different levels of experience in the field may have. This section later examines the scoring of impacts separately to identify potential barriers to implementation.

While the overall score provides a balanced perspective between probability and impact, the latter carries important information regarding the feasibility of business adoption of Virtual Coupling.

This points to the importance of considering these risks, even those with low probabilities

4.3.1 Range of responses

Our analysis looked initially at the range of responses, calculating the standard deviation (SD) for each risk. The standard deviation complements the average-based overall score in highlighting consensus or disagreements between the various responses for each risk. A high SD indicates that respondents provided very different responses, while a low SD indicates that the responses were close to the mean and that there was greater consensus. A table with all results analysed in this way can be found in Appendix B.

Some risks received a very large range of individual scores, such as risk 8.1 - Media/public suspicion regarding the ability to stop in the gap to the next train. That risk saw individual scores range from the absolute minimum (1) to the absolute maximum (100) between respondents and had an SD of 30.3. Similarly, risk 6.4 on the time to migrate systems to Virtual Coupling received individual scores between 3 and 100 for an SD of 27.9. On the other hand, some risks encountered more consensus where the range of individual scores was much smaller. One example was risk 4.12 on degraded operations being worse than current which received scores between 12 and 36 only with an SD of 10.5.

Table 4 lists the ten risks with the greatest standard deviation. Notably, half of the risks with the greatest standard deviation are also risks with the highest overall score. This might illustrate the distinct opinions over the feasibility or the cost-benefits of Virtual Coupling when compared to ETCS L3 Moving Block systems.

Another aspect that possibly highlights the distinct opinions is possibly the type of risks where respondents disagreed more. These risks are linked to the confidence on the ability to solve the technical and technological issues around Virtual Coupling. For example, risk 4.10 on the ability to operate platoons at complex layouts, or risk 4.6 in developing point switching technologies to cope with VC operations.

Table 4. Risks with the greatest standard deviation

RISK		Overall score	Standard Deviation
8.1	Media/public suspicious of trains that cannot stop in the gap to the next train	34.7	30.3
6.4	Migration to ETCS Level 3 with Moving Block may take a very long time	58.6	27.9
4.10	Trains can run closer on plain line but not in junction/station/complex layouts - thus limiting the benefit	46.6	27.7
7.1	Costs exceed the benefits	57.6	26.6
3.3	Emergence of disagreement over role of train operators and infrastructure managers in deployment	33.5	25.9
1.2	Excessive time elapses from proof of concept to defining actual specifications	46.8	25.5
4.6	VC will require a change to point switching technology	32.3	25.3
7.5	Uncertainty about compatibility with next generation of CCS	36.0	25.3

4.7	The added complexity of cooperative train control technologies needed to maximise benefits of Virtual Coupling creates unexpected system risks	48.0	24.7
4.9	Trains cannot run closer together than ETCS L3	35.7	24.0

On the other end of the spectrum, Table 5 shows the risks where there was greater consensus between the respondents, illustrated by the small standard deviation. One common aspect between all those is the fact they all received low overall scores and seem to relate to non-critical risks.

Table 5. Risks with the smallest standard deviation

RISK		Overall score	Standard Deviation
1.4	Failure to Integrate into EU/EUAR plan for standards	24.0	9.4
4.12	Degraded mode operation worse than current	21.7	10.5
9.4	Near misses during operations	23.3	12.9
4.3	Lack of availability of spectrum for Communication	25.2	13.8
4.11	Repeated failures during operation	20.5	13.9

Finally, our analysis in variance between respondents looked at the difference between the average (which forms the overall score), and the median of individual scores for each risk. While an additional layer on the analysis, this process can help identify overall scores that may have been affected by outliers (on both ends of the spectrum). Appendix B lists all findings, which are summarised in Table 6. These values are calculated as an absolute difference between the average and the mean, regardless of which one is greater.

Table 6. Five highest variations between average and median scores

RISK		Overall score	Median	Variance OS/Median
7.9	Passengers may not adjust to the different operations	14.0	6	57.1%
8.1	Media/public suspicious of trains that cannot stop in the gap to the next train	34.7	20	42.4%
7.5	Uncertainty about compatibility with next generation of CCS	36.0	25	30.6%
4.3	Lack of availability of spectrum for Communication	25.2	18	28.5%
3.3	Emergence of disagreement over role of train operators and infrastructure managers in deployment	33.5	24	28.5%

4.3.2. Results by level of expertise declared

The second part of this analysis looked at the responses given against the expertise of the respondents. The survey asked respondents to self-assign a level of expertise between limited (LIM), practitioner (PRAC), or expert (EXP) knowledge on the field. This provided us with a qualitative understanding of any potential influence that expertise levels could have on the perceived criticality of each risk.

Firstly, we counted the number of times where each of the expertise groups gave the highest

average score to a risk. For example, those with limited expertise gave an average score of 44.0 to Risk 1.1, while the practitioners and experts gave the risk average scores of 27.7 and 41.0. Therefore, the Limited expertise group was recorded as having awarded the highest average score for that risk.

Not all risks could be assessed in this manner. Of the 55 risks comprised in this task, four were added by individual respondents and therefore only had one score. The analysis was conducted on the remaining 51 risks where respondents from at least two segments responded. Of those, practitioners gave highest scores to 22 risks, those with limited knowledge gave highest scores to 19, and experts gave highest scores to 11. Table 7 lists the distribution of highest scores per expertise segment, listed by theme. The sum of counters actually totals 52 because both Limited and Expert groups gave equal average scores to risk 7.2.

Table 7. Distribution of highest scores per expertise segment

Theme	Incidence of highest scores		
	Limited	Practitioner	Expert
Standards	3	1	2
Supply side	3	1	0
Operations side	1	1	1
Technical	2	7	3
Regulatory	2	3	0
Transition/implementation issues	2	2	1
Business case	2	5	4
Public acceptance	1	0	0
Safety	3	2	0
TOTAL	19	22	11

While Practitioners gave highest scores most times, it is worth analysing the incidences per theme. Experts gave answers showing they are less concerned with uptake processes such as regulations, safety assurance, and public and business acceptance, whereas those with Limited expertise seemed to be more confident on the technology and the cost-benefits of Virtual Coupling. Practitioners, on the other hand, showed considerable caution on these two aspects of implementation.

Secondly, we looked for the variation in scores given by each segment. Greater variability highlights disagreement points, whereas smaller variations demonstrate consensus among the different levels of expertise. As shown in tables Table 8 and Table 9, there was a wide range of scores where we measured the difference between the highest and the lowest score of the three segments. Some risks had differences in scores of up to almost 37 points, where others almost showed unanimity with a difference of only 1 point between the highest and lowest scores.

Table 8. Risks with the greatest variance between expertise segments

Risk		Highest	Lowest	Difference
4.6	VC will require a change to point switching technology	57.3 (PRAC)	20.6 (EXP)	36.7
9.1	Accident during testing undermines confidence	44.7 (LIM)	11.8 (EXP)	32.9
8.1	Media/public suspicious of trains that cannot stop in the gap to the next train	56.3 (LIM)	25.3 (PRAC)	31.0
9.3	Near misses during testing	44.7 (LIM)	13.8 (EXP)	30.9
7.7	Insurers become reluctant to carry risks of solutions	52 (PRAC)	22 (EXP)	30.0

Table 9. Risks with the smallest variance between expertise segments

Risk		Highest	Lowest	Difference
7.8	Elapsed time between now and implementation may change business cases	52.0 (PRAC)	51.0 (EXP)	1.0
1.4	Failure to Integrate into EU/EUAR plan for standards	25.0 (EXP)	23.0 (PRAC)	2.0
4.12	Degraded mode operation worse than current	23.7 (LIM)	21.0 (PRAC & EXP)	2.7
6.4	Migration to ETCS Level 3 with Moving Block may take a very long time	59.7 (LIM)	56.7 (PRAC)	3.0
4.1	The system does not deliver the required outputs	43.8 (EXP)	40.7 (LIM & PRAC)	3.1

Finally, we analysed the different answers that each expertise group gave within each theme of the survey. Figure 2 illustrates the answers relating to Standards, considering the limited, practitioner, and expert levels, as well as the combined result. In half of the risks, those with limited expertise gave the highest scores, mostly relating to the different solutions that can potentially be applied to Virtual Coupling.

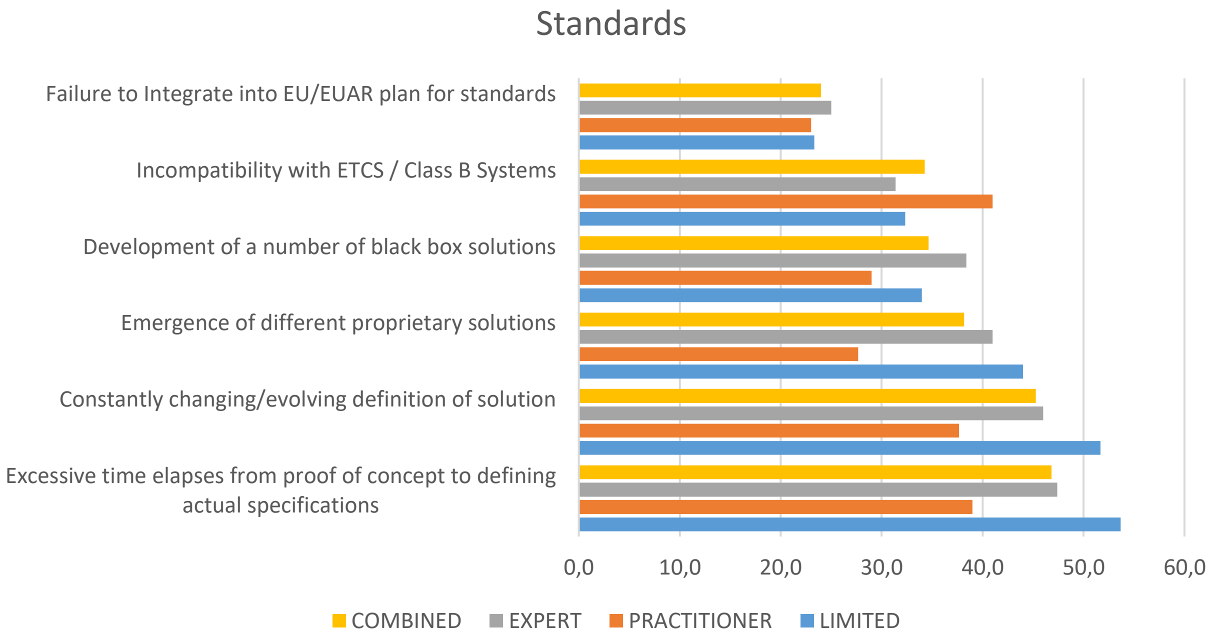

Figure 2. Responses per expertise for risks relating to Standards

Similar results were observed for risks on the supply side. In three of the four cases where all groups scored risks, those with limited expertise gave higher scores than the others. The risk about different suppliers developing solutions that are only compatible with their existing products/systems was added by one participant, and thus excluded from the comparison. Experts seemed particularly concerned about the risk of different suppliers developing different solutions and thus adding complication to the market. On the other hand, practitioners emphasise issues around IPR and failure to attract investors.

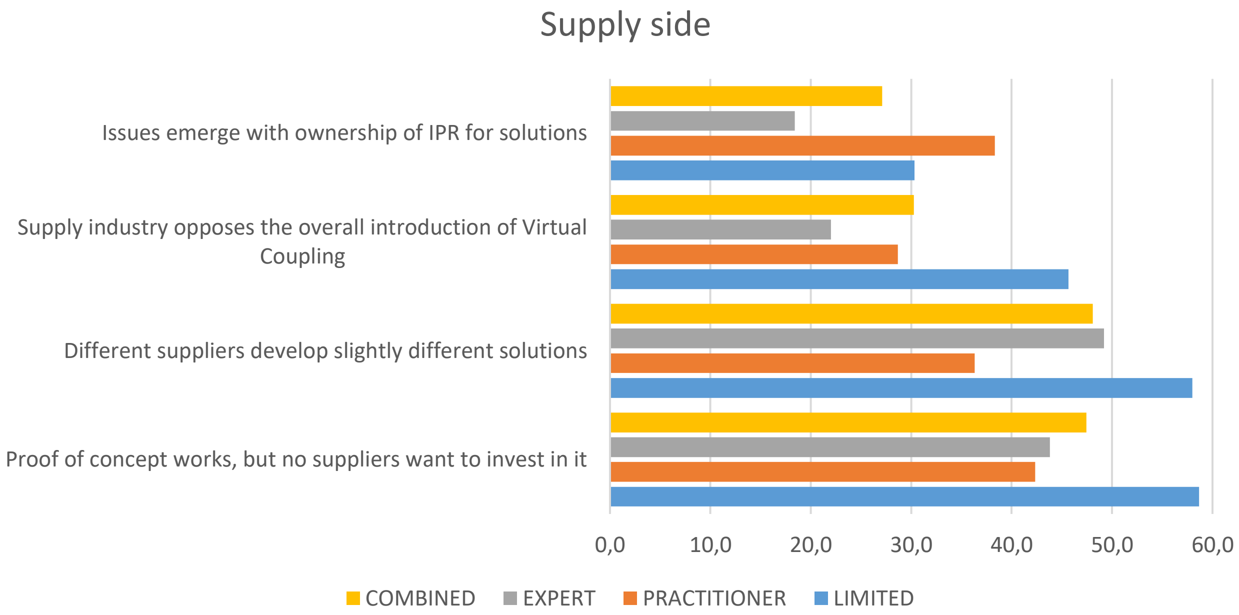

Figure 3. Responses per expertise for risks relating to Supply Side

On the risks associated with the operations side of implementation, each segment gave highest

scores to a different risk. Three risks have been listed on Figure 4, as the other three were added by individuals during the survey. This theme contains the highest ranked risk of the entire survey, relating to business and/or safety concerns preventing operators from implementing Virtual Coupling. Experts gave the highest score to this risk, with an average of 75.8 out of 100.

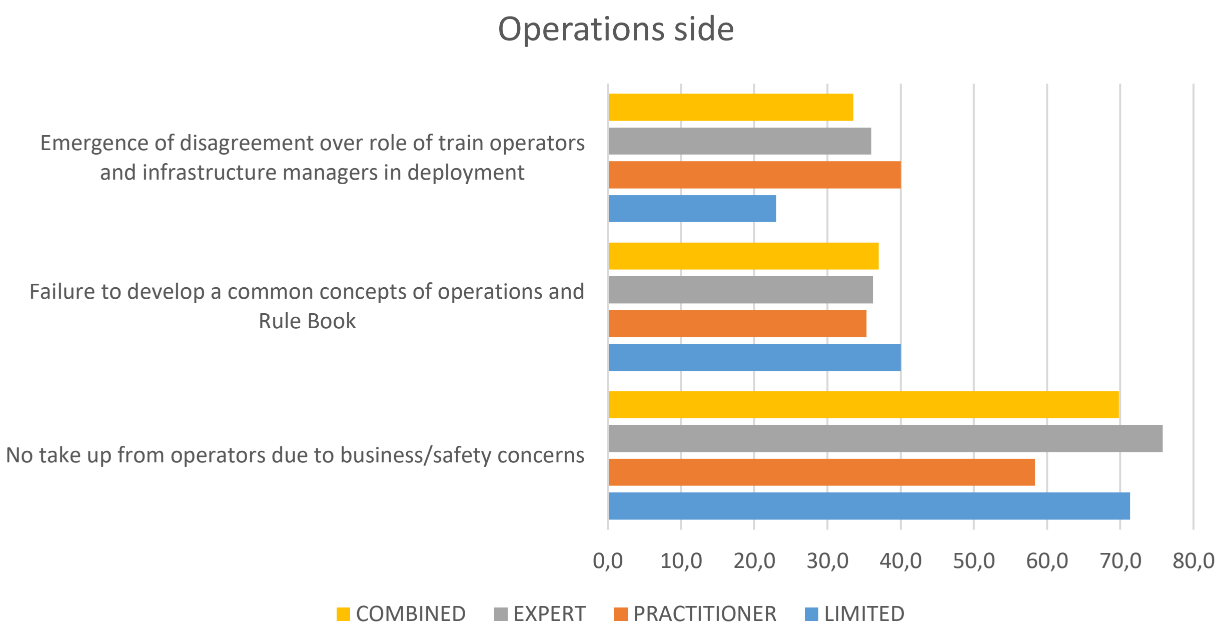

Figure 4. Responses per expertise for risks relating to Operations Side

The technical theme encapsulated the greatest number or risks for assessment and saw a wide range of responses amongst the three segments. Most of the answers showed certain consistency between the different levels of expertise, with the exception of risk 4.6 - VC will require a change to point switching technology, and risk 4.10 - Trains can run closer on plain line but not in junction/station/complex layouts - thus limiting the benefit. In the former, practitioners rated the risk much higher than the other two groups, whereas in the latter, those with limited experience rated the risk considerably lower than the more experienced groups.

Another observation from the responses show greater concerns over the complexity and complication of implementing Virtual Coupling rather than the technical feasibility of the technology. Experts in particular seem concerned with the cost-benefits of the solution, giving high scores to risks such as the need to upgrade existing on-board systems and adaptation of logical ICT systems (cost), and that trains can run closer on plain line but not in junction/station/complex layouts (benefit). The potential implications of such failures evidence the unlikely uptake of Virtual Coupling in a scenario where the costs outweigh the benefits.

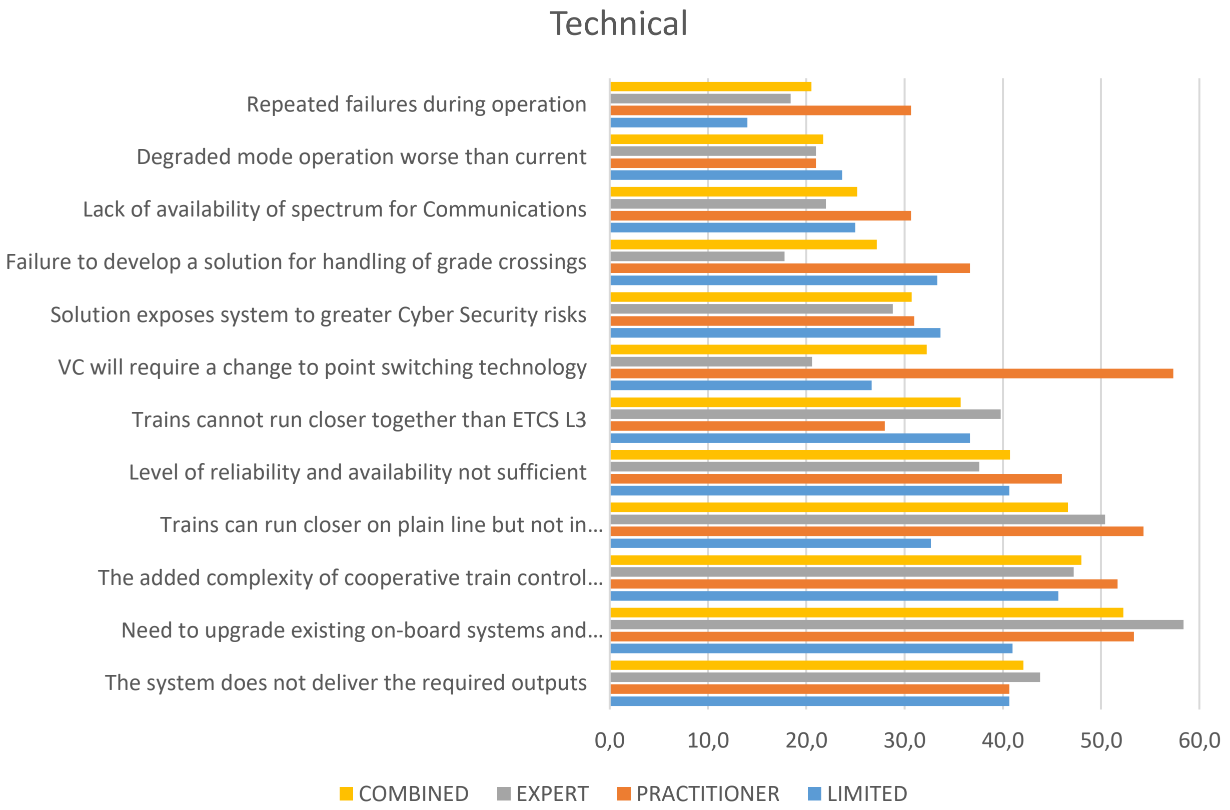

Figure 5. Responses per expertise for Technical risks

Regulatory risks received overall low scores compared to other themes, and the different segments seemed to agree on the majority of cases. The exceptions are the risk of non-fulfilment of the CSM-RA, and the working system not to be supported by the Commission. In both instances, the lowest scores were given by experts with a considerable gap with the scores given by the other two groups. One possible reading of this is that experts may assume that these two needs are addressed even before business implementation is discussed. In short, the uncertainty of market adoption cannot even be discussed if the technology is not approved by the regulators.

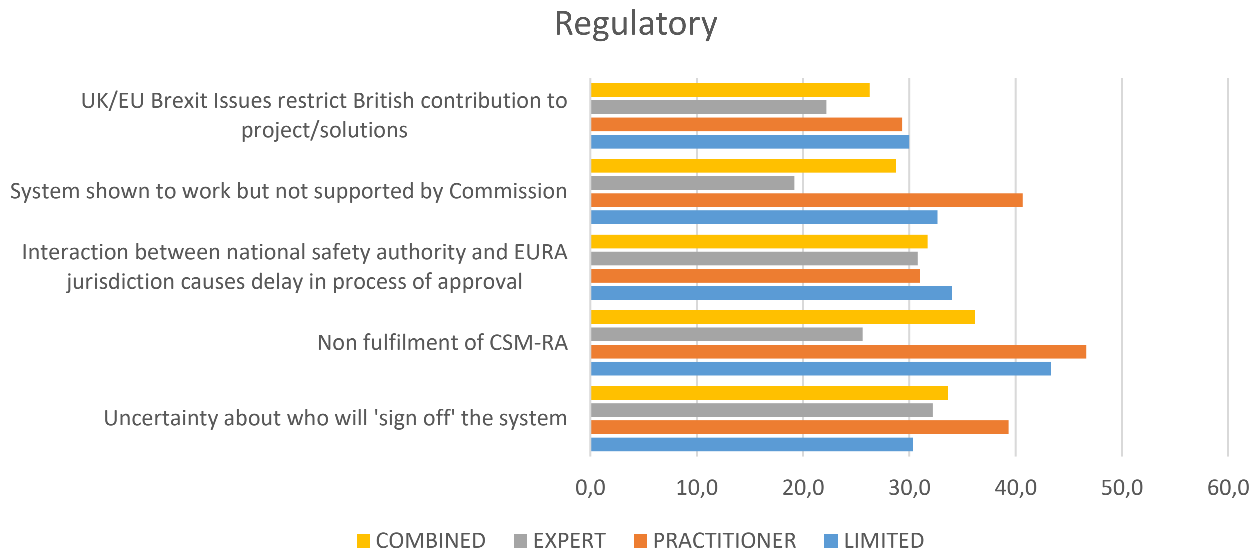

Figure 6. Responses per expertise for Regulatory risks

Under the theme of transition/implementation, one risk received consistent emphasis from the three different groups, in relation to the time taken to implement the technology. All groups seem to agree that the if the migration to ETCS Level 3 with Moving Block takes a very long time, and being the foundation to Virtual Coupling, it imposes serious risks to the implementation of the latter. Practitioners seemed more certain whether the impossibility to migrate to Moving Block would mean that Virtual Coupling becomes unfeasible. On the other hand, those with limited experience seemed to think that if promising routes already have the most modern signalling system, then the chances of Virtual Coupling providing a compelling business case are much lower.

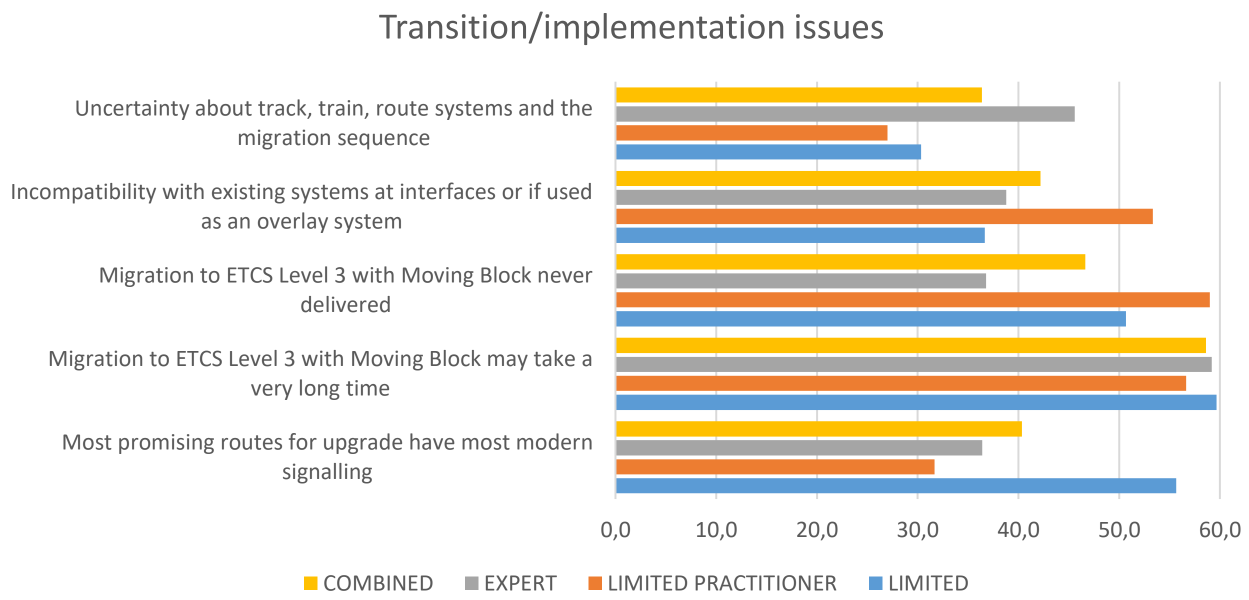

Figure 7. Responses per expertise for Transition/implementation issues

In the business case remit, general scores ranged from low to medium. Three of the risks were only assessed by practitioners and experts due to the iterations of the survey. Overall, the highest

scoring risks related to the cost-benefits of Virtual Coupling. Firstly, all three segments seemed to agree on the criticality of costs outweighing the benefits. Secondly, practitioners and experts also gave high scores to the event that the time elapsed between now and implementation changes business cases. This resonates with the highest scoring risk of the previous theme (transition/implementation issues) where the three groups gave high scores to the risk of migration to ETCS L3 taking a very long time or even never being delivered.

While there was agreement on the highest scorers, practitioners gave significantly higher scores to three risks when compared to the other two segments. There was a certain connection between them, where it can be read that uncertainty over costs and compatibility makes insurers reluctant to carry the risks for implementing the solutions, and it could stall deployment.

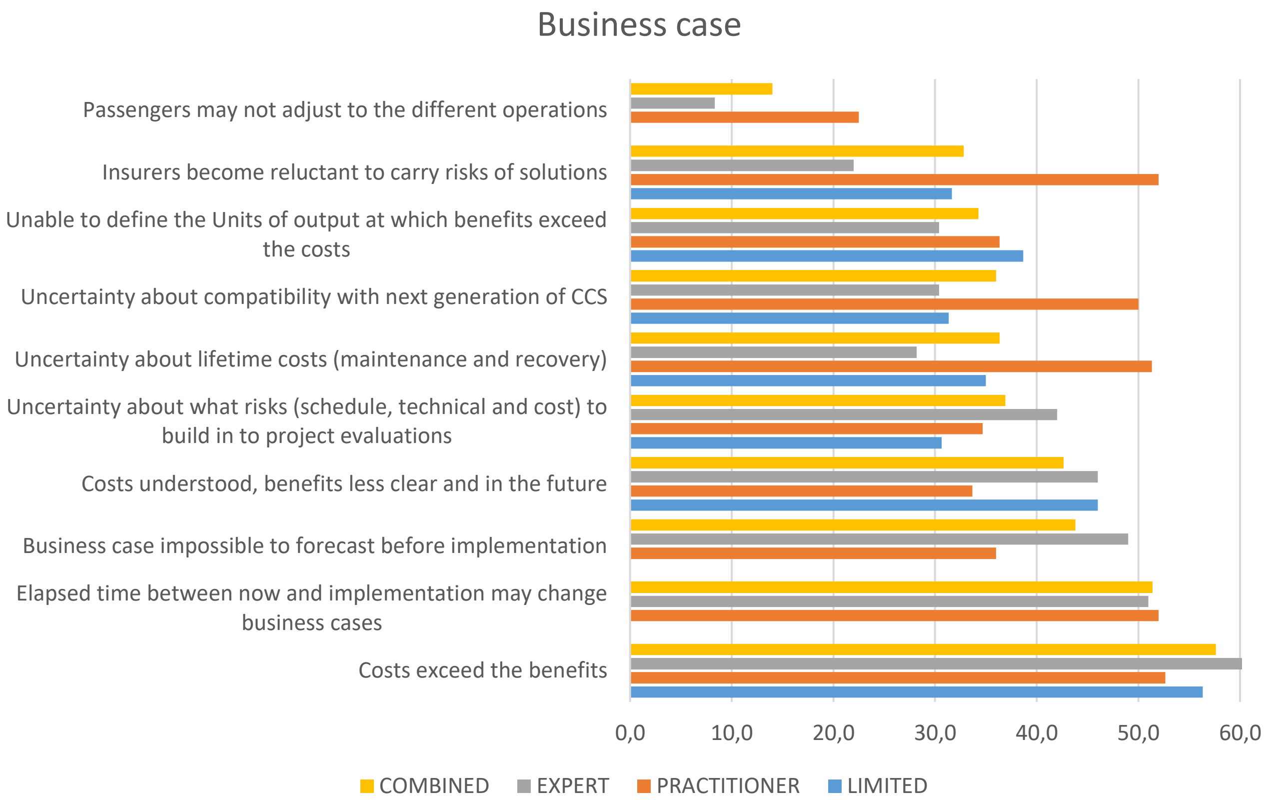

Figure 8. Responses per expertise for Business Case risks

One risk associated with public acceptance was included in the survey, and received mixed scores from the different segments. Experts and practitioners gave the impression that any suspicion from the media or public regarding the technology would not affect its implementation. On the other hand, those with limited experience gave a significantly higher score to the risk which may be a feel about this technology. Overall, the risk was seen as having low criticality, providing the technical trails do not lead to any safety events. .

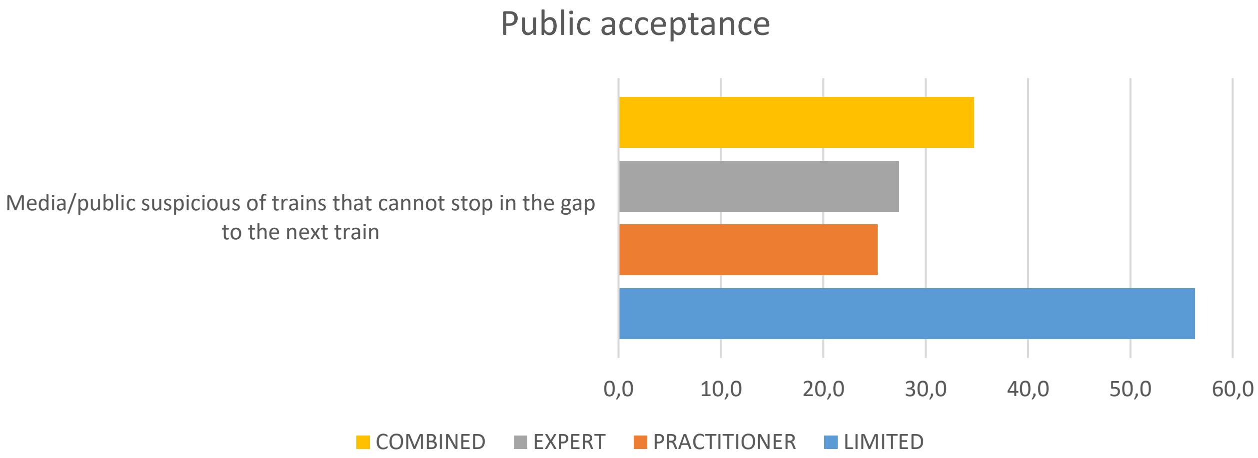

Figure 9. Responses per expertise for Public Acceptance risks

Finally, the theme of safety received relatively low scores across all its risks. While safety risks are critical in a safety-critical sector such as the railways, the results indicate that safety is not itself a business risk. Overall, experts gave the lowest scores, with most risks being scored below 20 out of 100. This reflects the technical experts view that the safety risks will be sufficiently managed during the development stage. Conversely, those with limited experience seemed to think that failures, near misses, and accidents during testing had a greater chance of undermining the confidence in the technology and stall its implementation. Thus, the respective weighting given to safety, reflect the absolute need for the technical and safety issues to be resolved before regulatory and investor support is sought.

Figure 10. Responses per expertise for Safety risks

5. Discussion

5.1. Most critical risks

The previous section looked at the overall scores that included both the probability and the impact of each risk. However, although some risks were judged to be low probabilities, in the view of many respondents, from all levels of expertise, their impact, should they occur, would potentially stall the implementation of Virtual Coupling.

We analysed the most critical factors from the incidence of high impact scores amongst respondents. The threshold chosen for considering a risk to be high impact was seven (on the scale from zero to ten). We then calculated the percentage of respondents that scored that risk as seven or above, based on the assumption that consensus over a risk being high impact would mean that it is a critical factor for consideration. Since consensus plays an important part in establishing criticality levels, we only considered risks that were scored by at least half of the participants. Of the 51 eligible risks analysed during the survey, there were 14 instances where more than 70% of respondents assigned an impact score of seven or more. These are listed on Table 10, and the full list can be found in Appendix C.

Following the overall results, risk 3.1 (No take up from operators due to business/safety concerns) of operators not taking up Virtual Coupling due to business and/or safety concerns was unanimously rated as a highly critical factor. It received a median impact score of 10, an average impact score of 9, and was rated seven or more by all respondents. However, the risk with the second highest percentage of respondents giving high impact scores did not follow the overall scores rankings (Table 2). Risk 2.1 of no suppliers wanting to invest in Virtual Coupling despite the proof of concept working had a median impact score of nine, an average score of 8.63, and was deemed critical by over 90% of the participants. This shows that there was consensus in the low probability of suppliers not investing in something that delivers benefits, but the impact of that happening would be severe. Even greater differences were observed for risks in the safety domain. Both risks 9.2 and 9.4 received overall low scores but high impact scores, highlighting the difference in perception between the probability and the impact of the risks.

Table 10. Risks with high incidence of high-impact scores

Risk		Median impact	% over or equal 7 in impact score
3.1	No take up from operators due to business/safety concerns	10	100%
2.1	Proof of concept works, but no suppliers want to invest in it	9	91%
4.2	Level of reliability and availability not sufficient	9	82%
5.3	Non fulfilment of CSM-RA	9	82%
9.2	Accident during live operation undermines confidence	9	82%
2.3	Supply industry opposes the overall introduction of Virtual Coupling	8	82%
4.1	The system does not deliver the required outputs	8	82%
4.3	Lack of availability of spectrum for Communications	8	82%
7.1	Costs exceed the benefits	8	82%
4.9	Trains cannot run closer together than ETCS L3	9	73%

6.3	Migration to ETCS Level 3 with Moving Block never delivered	9	73%
9.4	Near misses during operations	9	73%
6.4	Migration to ETCS Level 3 with Moving Block may take a very long time	7	73%
7.3	Unable to define the Units of output at which benefits exceed the costs	7	73%

We decided to measure the criticality of impacts by the percentage of impact scores equal or over seven rather than by the median or average to look for consistency in perception of barriers to implementation. As it can be observed on Table 10, there are risks with high median scores of nine, but 73% incidence of high scores. This shows that some respondents may have given high scores but others ranked them in the opposite direction.

The risks that consistently received high impact scores highlight the critical factors that could potentially delay or even prevent the implementation of Virtual Coupling in the European railway market. The three general topics raised from the results relate to the cost-benefit of the solution over ETCS L3, the reliability of the solution, and challenges over its implementation.

While several of the risks listed in Table 10 have been perceived as having low probability of happening, the severity of impact should they occur may jeopardise the entire feasibility of the solution, particularly as it will form part of the business evaluation of potential early implementers and investors.

Overcoming the barriers to the take up of the technology by reducing the risks highlighted in the survey requires a targeted approach. Accordingly, the next section discusses potential mitigation plans for the different markets.

5.1.1. Qualitative analysis of critical risks

While Table 10 provides an important evaluation of the most critical risks based on the median and incidence of scores, it is also important to observe specific instances where respondents may raise questions over the feasibility of Virtual Coupling. Using the responses collated in Appendix D, we looked for combinations of very high responses for both probability and impact.

The survey description mentioned that a score of 10 for probability means that the risk is virtually inevitable, and a score of 10 for impact means that the risk is devastating for the implementation of Virtual Coupling. If a respondent assigned a score of 10 for both probability and impact, it means that their view is that the risk is a certainty that will have a devastating impact to the project.

Obviously, the assignment of high scores of 9 and 10 carry a certain subjective understanding of the meaning behind the terms virtually inevitable (for probability) and devastating (for impact).

Nonetheless, a qualitative observation of the disaggregated responses can improve our reasoning in two ways: identify risks that were given those exceptionally high combinations more than once, and understand respondents' opinions on the matter. The first would point out risks where a high combination is not an outlier occurrence, and the latter will clarify whether a respondent is more or less sceptical about the possibility of a successful implementation of VC.

We looked the data for combinations of scores of 9 or 10. This means that we marked every instance where a respondent assigned either 9/9, 9/10, 10/9, or 10/10 for probability and impact respectively. Of the responses observed, two risks and two respondents stood out.

Firstly, as expected, risk 3.1 (No take up from operators due to business/safety concerns) received exceptionally high combinations by four of the eleven respondents. This highlights how critical the risk of 'no take up from operators due to business/safety concerns' is. Secondly, risk 7.1 of 'costs exceed the benefits' received high combinations by three respondents, indicating that it requires attention. These risks are interconnected as they relate to the reluctance that the industry, especially operators, may have in investing in the implementation of Virtual Coupling if the technology does not deliver enough benefits to justify the costs and the additional risks involved.

In terms of respondents, Respondent 9 seemed particularly sceptical of the feasibility of VC. The respondent, who self-identified as an expert in the field, assigned high combinations to 12 out of 51 risks. It can be inferred that the expert believes that there are various hurdles that are not only certain to happen but also that they will have a devastating impact on the implementation of the technology. Respondent 11, who self-identified as a practitioner, assigned high combinations to seven risks. The two respondents chose the same high combinations in three instances: risks 4.8 (Need to upgrade existing on-board systems and adaptation of logical ICT systems), 6.4 (Migration to ETCS Level 3 with Moving Block may take a very long time) , and 7.1 (Costs exceed the benefits).

While these occurrences may be influenced by a variety of subjective factors, they show specific points where those working in the sector believe that barriers to implementation will not be overcome.

5.2. Market segments

5.2.1. Urban

Based on the previous investigations of the MOVINGRAIL project, the urban segment seems to be the one that offers the fewest barriers to the implementation of Virtual Coupling, especially segregated high-capacity systems. Deliverable D4.2contains an evaluation of the costs and benefits of Virtual Coupling using Berlin's rapid transit system, the S-Bahn. The S-Bahn operates in a segregated form from other types of traffic, thus reducing the likelihood of collisions with objects or other vehicles on the tracks.

The segregated nature of rapid transit systems, usually run underground, provides a fruitful environment that can minimise the risks associated with running trains closer together. With that, the additional capacity may prove valuable to offset the costs in implementing such technology. Further, on the costs, many rapid transit systems already operate under CBTC (Communication Based Train Control) signalling, which is similar to ETCS Level 3. Therefore, the risks associated with the challenges in the transition to ETCS L3 are either reduced or removed, since the technology is present. Moreover, rapid transit systems tend to operate in simpler routes with fewer junctions and/or passing loops. The reduced complication of the network also mitigates some of the risks related to junctions and the respective loss of capacity.

Urban systems also tend to operate homogeneous fleets at similar speeds and stopping patterns, which facilitate the closer running proposed by Virtual Coupling. Deliverable D4.2 demonstrated capacity gains for rapid transit systems when already short headways are shortened even further. However, the impact of accidents in high capacity systems has been raised in risks 9.2 and 9.4, where any potential issues with safety could undermine confidence of investors, regulators and insurers.

With that, the implementation of Virtual Coupling to non-segregated urban systems encounters many of the high-impact risks highlighted by survey respondents. Firstly, there are certain operational concepts where the risk of running vehicles closer than at absolute braking distance may prevent operators from taking up the technology. Even if that is managed from a technical standpoint, the time and effort required to transition to ETCS L3 and further to Virtual Coupling may prove unfeasible and uneconomical.

5.2.2. Regional

MOVINGRAIL defines regional services as the less frequent routes that feed passengers onto the main lines of the network. These can be serviced by a variety of consists, ranging from one to 10 vehicles with a capacity of 140 to 1,800 spaces for passengers. In Europe, all railway lines are still equipped with fixed-block signalling systems, apart from urban systems where CBTC is installed. .

This means regional services may face greater implementation challenges since most also require first upgrading to ETCS L3 signalling systems. This process, as identified by survey respondents, may prove too costly or take too long to create a business case. In the UK and in many countries across the EU, many of the regional routes are subsidised, and the combination of costs and forecast demand is seen as unlikely to generate a positive business case, regardless of which party makes the investment. It would need very significant reductions in the implementation time and costs of the technology to increase the likelihood of adoption in this market segment.

Regional lines have to balance connectivity, speed, and capacity in connecting passengers to railway hubs. From a business point of view, this creates a paradox of servicing low-demand areas in a financially sustainable manner, but also coping with crowding on commuter corridors. In both scenarios, regional services face certain risks in the cost-benefit ratio of adopting Virtual Coupling technologies.

Simulations in Deliverable D4.2 demonstrate that Virtual Coupling could provide an increase in capacity of less than 2% over ETCS Level 3 moving block without an optimised train control for formation/decomposition of platoons. This is something that 73% of respondents had raised concerns about the extent that VC would increase capacity when compared to moving block signalling (risk 4.9). It also relates to risk 7.1 – costs exceed the benefits. In many regional railways, the technical maturity is still far from the most advanced available technologies. Therefore, the costs of upgrading lines to ETCS Level 3 must be taken into account.

More specifically, D4.2 highlights a technical aspect in regional lines that add to the criticality of business risks. In these lines, the difference between maximum line speed and turnout speed is significant, which means that platoons may face a continuum of speed variations that in turn reduce capacity gains of Virtual Coupling (risks 4.6 and 4.10). This is also raised on the roadmap

developed in D4.3 where switch technologies must be looked into to enable operators to reap the benefits of VC.

Finally, the business risks in regional lines seem to be accentuated by the lower demand that is observed when compared to main lines. Given that running ETCS Level 3 has the potential to be less costly than fixed-block signalling due to the reduction in trackside equipment, the determinant seems to lie on overall implementation costs against revenues over the operation period.

5.2.3. Main line

In contrast to regional services, main lines tend to receive a greater deal of attention in regards to capacity improvements. These arterial routes serve as the backbone of national networks and have been already operating at full capacity in some countries. The MOVINGRAIL project highlights that main lines tend to receive greater investment in maintaining infrastructure to higher standards in order to justify higher operating speeds. Moreover, in many countries these lines tend to have at least a double track and often contain multiple parallel tracks.

These aspects make main lines potential candidates for the implementation of Virtual Coupling. They require the additional capacity, where in turn the benefits may exceed the costs, mitigating risk 7.1. Furthermore, simulations from Deliverable D4.2 have shown that VC could expand capacity by 42% when compared to current signalling systems. What is even more compelling is that VC would bring a substantial capacity increase even when compared to ETCS Level 3, a jump of 14%. This can potentially mitigate risk 4.9 of trains not running closer than ETCS L3, which respondents rated as having a high-impact on implementation.

On the other hand, the risks involved in standardisation may play a larger part on these circumstances. In some countries, different operators share the use of main lines, and in some countries, the ownership structure also creates many separate stakeholders with responsibility for the infrastructure and various rolling stocks. The varying needs for investment and differences in where benefits fall becomes more complicated with multiple stakeholders.

This complication can generate several risks. Firstly, there is the issue of competition. As risk 3.5 highlights, operators may adopt different/incompatible systems. Second, even if the risks of standardisation are addressed (operators harmonise implementation), operators may refrain from coupling with competitors (risk 3.4). Third, different operators may find that the extra capacity is not made available to them at the sections and/or times where the additional demand exists.

Such complexity in the ownership structure seems to counterbalance the operational benefits at the technical level. For example, the multiple tracks available to main lines mitigate risks 4.6 and 4.10 that relate to junctions and the operation of complex layouts. However, the multiple stakeholders involved may raise issues on the solutions adopted (risks 1.1 and 2.2), which may affect the transition and implementation timescales.

Deliverable D4.3 highlighted that experts see the transition to ETCS Level 3 and subsequently to Virtual Coupling as a challenging task that will probably demand more time for main lines than other market segments. These views align with risks 6.3 and 6.4, in which respondents stated that if migration takes too long, it might affect the viability of Virtual Coupling.

Managing these risks depends on the ability to deliver the technologies effectively and in a timely manner. Accidents and near misses may reduce the confidence of operators to invest in the technologies and stall the implementation of Virtual Coupling altogether. Main lines seem to carry significant opportunities and challenges simultaneously.

5.2.4. High-speed

Under the increasing efforts to curb transport emissions, high-speed rail (HSR) lines have risen to prominence as an alternative to long distance road transport and regional flights. Deliverable D4.1 outlined the impact on demand that their construction has had in the mode share. The European Commission TSI lists high-speed lines as those that allow operations over 200 km/h (or 250 km/h for those specifically built for high-speed services).

The complexity of multiple actors seen in main lines is less pronounced on High Speed Lines, though the liberalisation of access to EU infrastructure may make this a temporary condition. Generally homogeneous fleets and single operator structures may facilitate the harmonisation of standards and solutions (risks 1.1 and 2.2). Moreover, D4.1 highlights that high-speed lines in Europe are generally equipped with ETCS Level 2 signalling, which partially addresses the concerns over the time for the transition to ETCS Level 3 and beyond (risks 6.3 and 6.4).

On the technical side, dedicated high-speed lines tend to have less complex layouts, enabling the operational benefits of VC to be more fully enjoyed. The simulations in D4.2 showed that ETCS Level 3 could increase capacity by 23% when compared to current systems, while Virtual Coupling could add a further 14%.

Considering the usually higher value of time of HSR passengers, this means that operators may find that benefits of increasing the capacity may exceed the costs and the risks associated with the further enhancement of technologies to Virtual Coupling (risk 7.1). However, with greater running speeds, the distances required for coupling and uncoupling safely (and thus not running at maximum speed) may lead to a counterbalance in added capacity.

HSR is also the area where risk 6.1 arises, where most promising lines are already running the most modern signalling systems (and therefore unlikely to be considered for upgrading for some time). This means that unless there is a clear demand for more frequent services, running trains closer together may not deliver additional benefits.

Similarly, high-speed lines epitomise the safety concerns over running trains closer than absolute braking distances. At these speeds, collisions could lead to catastrophic outcomes, so accidents and near misses during testing and operations (risks 9.1 to 9.4) become more critical in this market segment.

These safety challenges add to the anticipated duration of transition to ETCS Level 3 and Virtual Coupling, as illustrated in the roadmap of D4.3. There are greater demands on command, control, and signalling performance to ensure the appropriate level of reliability. On a positive side, survey respondents risk rankings suggested confidence about the compatibility of the next generation of CCS (risk 7.5).

5.2.5. Freight

Despite often sharing use of the railway network with passenger services, the business cases for freight operations require attention to particular aspects that surround that market segment. The most obvious is that, since it does not carry passengers, accident risks (between freight trains) can be measured solely on financial terms rather than the potential injuries and fatalities. The exception are services carrying dangerous goods, which may be excluded from the list of suitable candidates for platoon operation, or may have to run in platoons with extended distances (full braking curves) between the respective trains. With that, some may argue that freight services are more readily available to accept trains running closer than absolute braking distances.

The roadmap developed in D4.3 also positions freight as a market segment with shorter deployment and implementation timescales. Given the lower speeds usually operated, freight services may encounter fewer technical challenges to run under Virtual Coupling, maybe counterbalanced by the lower braking rates that apply to freight. Also, considering the small and competitive margins of the sector, often operated with no subsidies, the capacity improvements must be very clear to attract the confidence of operators and rolling stock owners to invest.

Simulations in Deliverable D4.2 estimate that Virtual Coupling could add 15% capacity on top of the benefits from ETCS Level 3 compared to current systems. This amount, if realised, mitigates the most important risks raised in this study, namely 3.1 and 7.1 that concern the benefits and costs for the take up of operators, although the ability to realise benefit from this capacity uplift _depends on many other factors, such as timetable slots and (speed) compatible trains to platoon with.

However, there are some other factors to take into account. Firstly, most freight services share the network with passenger services, with the exception of a few dedicated corridors on the European continent. With that, it becomes much more complex to evaluate whether Virtual Coupling would generate capacity gains or not. From a technical standpoint, freight trains are longer than passenger trains, and any difference in service speeds would in fact reduce line capacity as the slower train would dictate the pace. From a business perspective, when both types of services share the use of infrastructure, concerns over standard harmonisation, benefit realisation, and cost responsibilities become more blurred and difficult to estimate. For instance, even if a freight operator implemented VC technology, the allocation of extra slots does not depend solely on that stakeholder.

In fact, there may be a penalty that freight operators create in shared routes because their length may create issues with passing loops and the speeds that platoons can couple and uncouple. These issues relate very closely to risk 4.6 regarding the requirement for new switch technologies, and 4.10 of complex layouts preventing trains from running closer together. In that, it may be the case that platoons could not be formed between freight and passenger trains, but that would create conflicts on timetables.

This also relates to instances where a platoon or convoy would be formed of only freight trains. Depending on the route, it might be more beneficial to physically couple the trains rather than virtually in order to avoid the speed variations required to safely maintain distances when coupling and uncoupling.

5.2.6. All operators

With vertical separation between all types of train operators and infrastructure managers, the investment in the technology for virtual coupling will involve interventions in both types of asset – rolling stock and infrastructure. The means by which this investment is funded and returns secured is an area where further work is required, and while it may become appropriate to mandate fitting for new assets, the experience with ETCS installation suggests that retrofitting of existing rolling stock and infrastructure is a business challenge for both parties. This is because there is very little relationship between the investment needs and where and how the benefits flow.

6. Conclusion

6.1. Overall remarks

This deliverable looked at the business risks associated with the implementation of Virtual Coupling. VC is here understood as a technical and technological extension of Moving Block signalling, such as with ETCS Level 3, therefore the former cannot be implemented without the latter in place. This study used a four-stage approach to analyse these business risks. Firstly, the project partners compiled a list of risks organised in nine categories. Secondly, these risks were made into an online survey that was shared with a list of stakeholders involved in railway signalling and relevant areas. Using the survey's option to add risks to the list, three risks were suggested by respondents. Thirdly, preliminary results were presented at a virtual workshop with stakeholders, project partners, and the advisory board, where three more risks were suggested to be added to the survey. Finally, the analysis was conducted alongside the tasks leading to deliverables D4.2 and D4.3, as well as drawing from project X3RAIL-3.

The online survey containing 55 business risks in nine themes was completed by 11 participants from five different countries and the online workshop was attended by 23 participants. These included stakeholders with limited expertise in signalling (and VC), practitioners, and experts in the field. This deliverable analysed the responses from a multitude of angles to derive conclusions that would contribute to the other deliverables in MOVINGRAIL Work Package 4.

Of the risks that were rated the highest, the lack of confidence of operators in the benefits and safety of Virtual Coupling stood out by a significant margin. Risk 3.1 (No take up from operators due to business/safety concerns) topped both rankings of overall scores, and median impact scores. Other risks which attracted both high scores and median impact include the time taken to transition to ETCS Level 3, costs exceeding the benefits, and the reluctance of stakeholders to invest in VC even if it proves to work.

Table 11 lists the top overall scores with their associated median impact scores. Those highlighted are risks that appear on both top 10 lists. Most of the risks, on top of their high overall score, also received a median impact score of seven or above. It must be noted that some risks with high median impact scores did not appear on both lists because of a low percentage of respondents that scored them seven or higher.

Given that the most critical risks are associated with the take up of the technology from operators based on the returns on the investment, the implementation of Virtual Coupling can perhaps find its way in market segments where the extra capacity is already a requirement. Technical complexity is seen as a barrier to lines where infrastructure is shared and operators may not be able to use the extra capacity proportionally.

It was also observed that business risks cannot be entirely decoupled from technical risks, as the uptake of Virtual Coupling depends on the confidence in the technology itself. Most of the risks that were emphasised by participants relate to the technical hurdles being overcome so that the benefits would demonstrably exceed the costs.

Table 11. Top overall scores and respective median impact scores

RISK		Overall score	Median impact score
3.1	No take up from operators due to business/safety concerns	69.8	10
6.4	Migration to ETCS Level 3 with Moving Block may take a very long time	58.6	7
7.1	Costs exceed the benefits	57.6	8
4.8	Need to upgrade existing on-board systems and adaptation of logical ICT systems	52.3	6
7.8	Elapsed time between now and implementation may change business cases	51.4	7
2.2	Different suppliers develop slightly different solutions	48.1	7
4.7	The added complexity of cooperative train control technologies needed to maximise benefits of Virtual Coupling creates unexpected system risks	48.0	7
2.1	Proof of concept works, but no suppliers want to invest in it	47.5	9
1.2	Excessive time elapses from proof of concept to defining actual specifications	46.8	7
4.10	Trains can run closer on plain line but not in junction/station/complex layouts - thus limiting the benefit	46.6	7

6.2. General Conclusions

In the work undertaken to consider business risks, the overall findings are that the technical challenges and safety issues have to be resolved in a manner that will give operators, suppliers, investors and regulators complete confidence in the system, while delivering cost effective technical solutions. If this cannot be achieved, there will be no take up of the technology. So the focus of further work should be on demonstrating that capacity can be enhanced through safe, technically sound and cost effective solutions to a level of assurance that operators and investors will be attracted to the benefits of increased capacity and the costs of getting there.

The most striking example of a risk that has been brought to the attention of this research, through a dialogue with the Shift2Rail project X2RAIL-3, is the potential for a rear end collision of high speed trains in the event of the leading train rapidly decelerating at an embankment slip or other immovable obstruction. While this is not itself a business risk, it helps to highlight the issues that potential first adopters and investors would have to consider. It appears to the participants in this work package that this risk can only be overcome in one of three ways:

a) By configuring dedicated infrastructure in such a way that there is no possibility (or an incredibly low probability) of the risk arising

b) By making the technical specification for VC such that the distance between trains in a platoon is always greater than the emergency braking distance plus a safety margin (in which case this might offer only marginal capacity gains above ETCS L3)
c) By Regulators and Government accepting and legislating that it is acceptable to operate VC with this risk extant.

There is likely to be the most benefit from investing in corridors that are, or are predicted to have significant capacity constraints, which VC can make a significant increase to. This means that rural routes and those that have a significant mixed traffic (i.e. freight and mainline passenger) are not suggested to be candidates for early adoption. Routes that could be considered for early adoption would include some or all of the following characteristics: Captive rolling stock fleets, homogenous train services with similar or identical service speeds, low numbers of junctions, few intermediate stations, existing technical barriers to running more and longer trains, coupled with robust forecasts of growing demand which cannot be met with existing technology and operations.

APPENDIX A – Overall score rankings

Standards		
RISK		Overall score
1.2	Excessive time elapses from proof of concept to defining actual specifications	46.8
1.5	Constantly changing/evolving definition of solution	45.3
1.1	Emergence of different proprietary solutions	38.2
1.4	Development of a number of black box solutions	34.6
1.5	Incompatibility with ETCS / Class B Systems	34.3
1.6	Failure to Integrate into EU/EUAR plan for standards	24.0

Supply side		
RISK		Overall score
2.2	Different suppliers develop slightly different solutions	48.1
2.1	Proof of concept works, but no suppliers want to invest in it	47.5
2.5	Different suppliers develop solutions compatible only with their existing products/systems	42
2.3	Supply industry opposes the overall introduction of Virtual Coupling	30.3
2.4	Issues emerge with ownership of IPR for solutions	27.1

Operations side		
RISK		Overall score
3.5	Operators want so many different/incompatible functions that the system is too complex and/or expensive to develop	80
3.1	No take up from operators due to business/safety concerns	69.8
3.4	No take up from operators due to competition (don't want to be coupled to a competitive train operator)	42
3.6	Operators unable to derive tangible commercial or customer benefits from the technology	40
3.2	Failure to develop a common concepts of operations and Rule Book	37
3.3	Emergence of disagreement over role of train operators and infrastructure managers in deployment	33.5

Technical	
RISK	Overall score

4.8	Need to upgrade existing on-board systems and adaptation of logical ICT systems	52.3
4.7	The added complexity of cooperative train control technologies needed to maximise benefits of Virtual Coupling creates unexpected system risks	48.0
4.10	The system does not deliver the required outputs	46.6
4.1	Trains can run closer on plain line but not in junction/station/complex layouts - thus limiting the benefit	42.1
4.2	Level of reliability and availability not sufficient	40.7
4.9	Trains cannot run closer together than ETCS L3	35.7
4.6	VC will require a change to point switching technology	32.3
4.4	Solution exposes system to greater Cyber Security risks	30.7
4.5	Failure to develop a solution for handling of grade crossings	27.2
4.3	Lack of availability of spectrum for Communications	25.2
4.12	Degraded mode operation worse than current	21.7
4.11	Repeated failures during operation	20.5

Regulatory		
RISK		Overall score
5.3	Non fulfilment of CSM-RA	36.2
5.1	Uncertainty about who will 'sign off' the system	33.6
5.2	Interaction between national safety authority and EURA jurisdiction causes delay in process of approval	31.7
5.5	System shown to work but not supported by Commission	28.7
5.4	UK/EU Brexit Issues restrict British contribution to project/solutions	26.3

Transition / implementation issues		
RISK		Overall score
6.4	Migration to ETCS Level 3 with Moving Block may take a very long time	58.6
6.3	Migration to ETCS Level 3 with Moving Block never delivered	46.6
6.2	Incompatibility with existing systems at interfaces or if used as an overlay system	42.2
6.1	Most promising routes for upgrade have most modern signalling	40.4
6.5	Uncertainty about track, train, route systems and the migration sequence	36.4

Business case	
RISK	Overall score

7.1	Costs exceed the benefits	57.6
7.8	Elapsed time between now and implementation may change business cases	51.4
7.10	Business case impossible to forecast before implementation	43.8
7.2	Costs understood, benefits less clear and in the future	42.6
7.6	Uncertainty about what risks (schedule, technical and cost) to build in to project evaluations	36.9
7.4	Uncertainty about lifetime costs (maintenance and recovery)	36.4
7.5	Uncertainty about compatibility with next generation of CCS	36.0
7.3	Unable to define the Units of output at which benefits exceed the costs	34.3
7.7	Insurers become reluctant to carry risks of solutions	32.8
7.9	Passengers may not adjust to the different operations	14.0

Media acceptance		
RISK		Overall score
8.1	Media/public suspicious of trains that cannot stop in the gap to the next train	34.7

Safety		
RISK		Overall score
9.5	Repeated failures not leading to incidents	33.3
9.3	Near misses during testing	27.5
9.1	Accident during testing undermines confidence	25.5
9.2	Accident during live operation undermines confidence	23.9
9.4	Near misses during operations	23.3

APPENDIX B – Standard deviation, medians, and median variation

	RISK	AVERAGE	Standard Deviation	MEDIAN	Variance between AVG and MED
	Standards				
1.1	Emergence of different proprietary solutions	38.2	15.9	42	10.0%
1.2	Excessive time elapses from proof of concept to defining actual specifications	46.8	25.5	49	4.7%
1.3	Development of a number of black box solutions	34.6	17.5	30	13.4%
1.4	Failure to Integrate into EU/EUAR plan for standards	24.0	9.4	25	4.2%
1.5	Constantly changing/evolving definition of solution	45.3	16.7	48	6.0%
1.6	Incompatibility with ETCS / Class B Systems	34.3	17.8	27	21.2%
	Supply side				
2.1	Proof of concept works, but no suppliers want to invest in it	47.5	17.3	45	5.2%
2.2	Different suppliers develop slightly different solutions	48.1	19.3	54	12.3%
2.3	Supply industry opposes the overall introduction of Virtual Coupling	30.3	17.8	32	5.7%
2.4	Issues emerge with ownership of IPR for solutions	27.1	16.1	21	22.5%
2.5	Different suppliers develop solutions compatible only with their existing products/systems	42.0	0.0	42	0.0%
	Operations side				
3.1	No take up from operators due to business/safety concerns	69.8	23.5	72	3.1%
3.2	Failure to develop a common concepts of operations and Rule Book	37.0	17.6	36	2.7%
3.3	Emergence of disagreement over role of train operators and infrastructure managers in deployment	33.5	25.9	24	28.5%
3.4	No take up from operators due to competition (don't want to be coupled to a competitive train operator)	42.0	0.0	42	0.0%
3.5	Operators want so many different/incompatible functions that the system is too complex and/or expensive to develop	80.0	0.0	80	0.0%
3.6	Operators unable to derive tangible commercial or customer benefits from the technology	40.0	0.0	40	0.0%
	Technical				
4.1	The system does not deliver the required outputs	42.1	22.5	45	6.9%
4.2	Level of reliability and availability not sufficient	40.7	22.1	42	3.1%

4.3	Lack of availability of spectrum for Communications	25.2	13.8	18	28.5%
4.4	Solution exposes system to greater Cyber Security risks	30.7	20.8	27	12.1%
4.5	Failure to develop a solution for handling of grade crossings	27.2	20.1	24	11.7%
4.6	VC will require a change to point switching technology	32.3	25.3	30	7.0%
4.7	The added complexity of cooperative train control technologies needed to maximise benefits of Virtual Coupling creates unexpected system risks	48.0	24.7	48	0.0%
4.8	Need to upgrade existing on-board systems and adaptation of logical ICT systems	52.3	23.8	42	19.7%
4.9	Trains cannot run closer together than ETCS L3	35.7	24.0	27	24.4%
4.10	Trains can run closer on plain line but not in junction/station/complex layouts - thus limiting the benefit	46.6	27.7	49	5.1%
4.11	Repeated failures during operation	20.5	13.9	21	2.2%
4.12	Degraded mode operation worse than current	21.7	10.5	20	7.9%
	Regulatory				
5.1	Uncertainty about who will 'sign off' the system	33.6	17.5	42	24.9%
5.2	Interaction between national safety authority and EURA jurisdiction causes delay in process of approval	31.7	21.6	24	24.4%
5.3	Non fulfilment of CSM-RA	36.2	17.2	40	10.6%
5.4	UK/EU Brexit Issues restrict British contribution to project/solutions	26.3	14.7	20	23.9%
5.5	System shown to work but not supported by Commission	28.7	17.4	27	6.0%
	Transition/implementation issues				
6.1	Most promising routes for upgrade have most modern signalling	40.4	22.2	40	0.9%
6.2	Incompatibility with existing systems at interfaces or if used as an overlay system	42.2	20.5	36	14.7%
6.3	Migration to ETCS Level 3 with Moving Block never delivered	46.6	23.9	45	3.5%
6.4	Migration to ETCS Level 3 with Moving Block may take a very long time	58.6	27.9	60	2.3%
6.5	Uncertainty about track, train, route systems and the migration sequence	36.4	17.0	30	17.5%
	Business case				
7.1	Costs exceed the benefits	57.6	26.6	56	2.8%
7.2	Costs understood, benefits less clear and in the future	42.6	18.6	42	1.5%
7.3	Unable to define the Units of output at which benefits exceed the costs	34.3	16.8	28	18.3%

7.4	Uncertainty about lifetime costs (maintenance and recovery)	36.4	16.3	35	3.8%
7.5	Uncertainty about compatibility with next generation of CCS	36.0	25.3	25	30.6%
7.6	Uncertainty about what risks (schedule, technical and cost) to build in to project evaluations	36.9	20.4	28	24.1%
7.7	Insurers become reluctant to carry risks of solutions	32.8	21.2	25	23.8%
7.8	Elapsed time between now and implementation may change business cases	51.4	19.3	49	4.7%
7.9	Passengers may not adjust to the different operations	14.0	14.2	6	57.1%
7.10	Business case impossible to forecast before implementation	43.8	22.7	48	9.6%
	Public acceptance				
8.1	Media/public suspicious of trains that cannot stop in the gap to the next train	34.7	30.3	20	42.4%
	Safety				
9.1	Accident during testing undermines confidence	25.5	15.5	21	17.8%
9.2	Accident during live operation undermines confidence	23.9	14.0	20	16.3%
9.3	Near mIsses during testing	27.5	15.8	20	27.4%
9.4	Near misses during operations	23.3	12.9	18	22.7%
9.5	Repeated failures not leading to incidents	33.3	16.2	36	8.2%

APPENDIX C – Incidence of high impact scores

	RISK	Limited		Practitioner		Expert		Combined	
		Median impact	% over or equal 7 in impact	Median impact	% over or equal 7 in impact	Median impact	% over or equal 7 in impact	Median impact	% over or equal 7 in impact
	Standards								
1.1	Emergence of different proprietary solutions	6	33%	4	50%	7	80%	7	55%
1.2	Excessive time elapses from proof of concept to defining actual specifications	8	100%	4	50%	7	60%	7	64%
1.3	Development of a number of black box solutions	7	67%	5	0%	8	60%	5	45%
1.4	Failure to Integrate into EU/EUAR plan for standards	5	0%	6	50%	7	60%	5	36%
1.5	Constantly changing/evolving definition of solution	7	100%	5	50%	8	60%	7	64%
1.6	Incompatibility with ETCS / Class B Systems	6	33%	8	100%	8	60%	8	64%
	Supply side								
2.1	Proof of concept works, but no suppliers want to invest in it	10	100%	9	100%	9	80%	9	91%
2.2	Different suppliers develop slightly different solutions	7	67%	4	33%	7	60%	7	55%
2.3	Supply industry opposes the overall introduction of Virtual Coupling	8	100%	9	100%	8	60%	8	82%
2.4	Issues emerge with ownership of IPR for solutions	7	67%	6	33%	5	0%	5	27%
	Operations side								
3.1	No take up from operators due to business/safety concerns	10	100%	10	100%	9	100%	10	100%
3.2	Failure to develop a common concepts of operations and Rule Book	5	33%	8	100%	8	60%	7	64%
3.3	Emergence of disagreement over role of train operators and infrastructure managers in deployment	6	33%	4	33%	6	40%	6	36%
	Technical								
4.1	The system does not deliver the required outputs	8	100%	9	100%	8	60%	8	82%
4.2	Level of reliability and availability not sufficient	7	67%	10	100%	9	80%	9	82%
4.3	Lack of availability of spectrum for Communications	7	67%	8	100%	8	80%	8	82%
4.4	Solution exposes system to greater Cyber Security risks	7	100%	8	67%	5	40%	7	64%
4.5	Failure to develop a solution for handling of grade crossings	6	33%	8	67%	8	60%	7	55%
4.6	VC will require a change to point switching technology	7	67%	8	100%	4	40%	8	64%

4.7	The added complexity of cooperative train control technologies needed to maximise benefits of Virtual Coupling creates unexpected system risks	8	100%	6	33%	7	60%	7	64%
4.8	Need to upgrade existing on-board systems and adaptation of logical ICT systems	5	33%	4	33%	6	40%	6	36%
4.9	Trains cannot run closer together than ETCS L3	8	67%	9	100%	8	60%	9	73%
4.10	Trains can run closer on plain line but not in junction/station/complex layouts - thus limiting the benefit	7	67%	6	33%	8	60%	7	55%
4.11	Repeated failures during operation	7	67%	9	67%	7	60%	7	64%
4.12	Degraded mode operation worse than current	6.5	33%	5	0%	6	40%	6	27%
	Regulatory								
5.1	Uncertainty about who will 'sign off' the system	6	33%	9	67%	7	80%	7	64%
5.2	Interaction between national safety authority and EURA jurisdiction causes delay in process of approval	6	33%	6	33%	6	40%	6	36%
5.3	Non fulfilment of CSM-RA	10	100%	10	100%	8	60%	9	82%
5.4	UK/EU Brexit Issues restrict British contribution to project/solutions	3	33%	4	0%	5	20%	4	18%
5.5	System shown to work but not supported by Commission	10	67%	8	67%	7	60%	7	64%
	Transition/implementation issues								
6.1	Most promising routes for upgrade have most modern signalling	8	67%	5	33%	5	40%	5	45%
6.2	Incompatibility with existing systems at interfaces or if used as an overlay system	6	33%	8	67%	6	40%	6	45%
6.3	Migration to ETCS Level 3 with Moving Block never delivered	8	67%	10	100%	9	60%	9	73%
6.4	Migration to ETCS Level 3 with Moving Block may take a very long time	7	100%	6	33%	9	80%	7	73%
6.5	Uncertainty about track, train, route systems and the migration sequence	5	0%	5	0%	8	80%	6	36%
	Business case								
7.1	Costs exceed the benefits	7	100%	9	100%	10	60%	8	82%
7.2	Costs understood, benefits less clear and in the future	7	67%	8	67%	7	60%	7	64%
7.3	Unable to define the Units of output at which benefits exceed the costs	7	67%	8	100%	7	60%	7	73%
7.4	Uncertainty about lifetime costs (maintenance and recovery)	5	33%	8	67%	6	20%	6	36%
7.5	Uncertainty about compatibility with next generation of CCS	7	67%	5	33%	7	60%	7	55%

7.6	Uncertainty about what risks (schedule, technical and cost) to build in to project evaluations	5	33%	6	33%	6	40%	6	36%
7.7	Insurers become reluctant to carry risks of solutions	6	33%	9	67%	5	20%	6	36%
7.8	Elapsed time between now and implementation may change business cases		0%	5.5	33%	7	40%	7	27%
7.9	Passengers may not adjust to the different operations		0%	7.5	33%	3	0%	5	9%
7.10	Business case impossible to forecast before implementation		0%	8	67%	9	40%	8	36%
	Public acceptance								
8.1	Media/public suspicious of trains that cannot stop in the gap to the next train	8	100%	4	0%	5	20%	5	36%
	Safety								
9.1	Accident during testing undermines confidence	9	100%	5	33%	6	40%	7	55%
9.2	Accident during live operation undermines confidence	10	100%	10	67%	9	80%	9	82%
9.3	Near mIsses during testing	6	33%	5	33%	5	20%	5	27%
9.4	Near misses during operations	9	100%	9	67%	9	60%	9	73%
9.5	Repeated failures not leading to incidents	6	33%	7	67%	7	60%	6.5	45%

APPENDIX D – Individual responses

R: Respondent;
Lim: Limited expertise; Prac: Practitioner; Exp: Expert;
P: Probability; I: Impact

RISK		R#1		R#2		R#3		R#4		R#5		R#6		R#7		R#8		R#9		R#10		R#11	
		Lim		Exp		Prac		Lim		Lim		Exp		Exp		Prac		Exp		Exp		Prac	
		P	I	P	I	P	I	P	I	P	I	P	I	P	I	P	I	P	I	P	I	P	I
Standards																							
1.1	Emergence of different proprietary solutions	6	8	3	3	8	4	7	6	7	6	5	7	8	8	3	3	7	7	6	8	6	7
1.2	Excessive time elapses from proof of concept to defining actual specifications	7	8	2	3	8	4	7	7	7	8	9	8	4	6	7	3	10	10	5	7	8	8
1.3	Development of a number of black box solutions	7	7	2	2	6	5	5	5	4	7	8	8	8	8	9	3	5	4	5	8	6	5
1.4	Failure to Integrate into EU/EUAR plan for standards	4	5	3	3	3	6	5	5	5	5	4	8	4	7	3	3	8	4	3	8	6	7
1.5	Constantly changing/evolving definition of solution	8	8	4	4	6	5	5	7	8	7	8	8	6	5	7	5	9	8	6	8	6	8
1.6	Incompatibility with ETCS / Class B Systems	5	5	3	8	2	8	4	6	6	8	3	6	4	10	3	9	8	6	3	9	10	8
Supply side																							
2.1	Proof of concept works, but no suppliers want to invest in it	5	10	5	5	5	8	7	10	7	8	5	9	4	7	3	9	9	9	4	10	6	10
2.2	Different suppliers develop slightly different solutions	8	8	9	2	8	4	10	7	8	5	6	9	8	4	7	3	10	7	9	8	8	7
2.3	Supply industry opposes the overall introduction of Virtual Coupling	5	7	1	8	2	9	7	10	4	8	4	8	3	6	2	9	7	6	1	10	5	10
2.4	Issues emerge with ownership of IPR for solutions	5	7	3	3	4	6	5	8	4	4	3	6	3	5	7	3	5	4	6	5	10	7
2.5	Different suppliers develop solutions compatible only with their existing products/systems																			7	6		

Operations side																							
3.1	No take up from operators due to business/safety concerns	3	8	8	7	5	7	10	10	9	10	9	9	9	8	6	10	10	10	7	10	8	10
3.2	Failure to develop a common concepts of operations and Rule Book	8	3	3	2	4	8	8	7	8	5	4	9	10	3	2	7	5	9	8	8	6	10
3.3	Emergence of disagreement over role of train operators and infrastructure managers in deployment	3	3	6	2	9	4	3	8	6	6	4	6	9	8	2	2	4	2	8	8	8	10
3.4	No take up from operators due to competition (don't want to be coupled to a competitive train operator)					6	7																
3.5	Operators want so many different/incompatible functions that the system is too complex and/or expensive to develop																			8	10		
3.6	Operators unable to derive tangible commercial or customer benefits from the technology																			5	8		
Technical																							
4.1	The system does not deliver the required outputs	5	10	3	3	4	8	3	8	6	8	5	8	5	4	5	9	10	10	5	10	5	9
4.2	Level of reliability and availability not sufficient	8	7	2	2	6	10	7	6	3	8	2	9	5	7	2	9	9	9	5	10	6	10
4.3	Lack of availability of spectrum for Communications	5	5	2	9	2	8	4	9	2	7	2	8	3	5	2	8	3	7	4	10	6	10
4.4	Solution exposes system to greater Cyber Security risks	7	7	2	2	3	9	3	8	4	7	2	7	3	5	2	8	6	5	9	9	10	5
4.5	Failure to develop a solution for handling of grade crossings	8	6	4	2	2	10	4	6	4	7	2	8	3	3	2	5	4	8	3	8	10	8
4.6	VC will require a change to point switching technology	5	5	3	3	5	8	1	7	6	8	2	4	4	4	4	8	3	10	5	8	10	10
4.7	The added complexity of cooperative train control technologies needed to maximise benefits of Virtual Coupling creates unexpected system risks	7	8	3	3	5	6	7	7	4	8	8	9	8	6	5	5	8	9	5	7	10	10
4.8	Need to upgrade existing on-board systems and adaptation of logical ICT systems	5	5	9	6	10	3	10	7	7	4	9	6	7	6	10	4	10	10	6	7	9	10
4.9	Trains cannot run closer together than ETCS L3			6	4	3	9	8	7	6	9	8	8	1	3	3	9	9	9	3	9	3	10
4.10	Trains can run closer on plain line but not in junction/station/complex layouts - thus limiting the benefit			9	5	6	6	7	7	7	7	8	8	3	3	9	3	8	10	6	9	10	10

4.11	Repeated failures during operation			3	7	4	9	3	7	3	7	2	9	2	3	2	3	3	5	4	8	5	10
4.12	Degraded mode operation worse than current			5	4	3	6	6	6	5	7	3	7	6	6	4	5	2	6	2	8	5	5
Regulatory																							
5.1	Uncertainty about who will 'sign off' the system	5	5	4	3	6	9	7	6	3	8	2	8	7	7	2	2	6	7	6	7	6	10
5.2	Interaction between national safety authority and EURA jurisdiction causes delay in process of approval	4	6	4	3	3	7	6	9	4	6	3	6	1	1	8	3	9	9	6	7	8	6
5.3	Non fulfilment of CSM-RA	4	10	2	9	6	10	5	8	5	10	6	9	5	5	2	10	3	5	2	8	6	10
5.4	UK/EU Brexit Issues restrict British contribution to project/solutions	6	3	3	5	3	4	6	9	6	3	5	8	2	3	7	4	6	5	5	4	8	6
5.5	System shown to work but not supported by Commission	3	10	2	5	7	8	5	10	3	6	3	9	1	3	4	4	6	7	2	7	5	10
Transition/implementation issues																							
6.1	Most promising routes for upgrade have most modern signalling	8	8	5	1	7	7	7	9	8	5	7	9	6	5	7	3	8	9	3	4	5	5
6.2	Incompatibility with existing systems at interfaces or if used as an overlay system	5	5	9	4	7	8	6	6	7	7	3	9	7	3	8	3	10	8	5	6	8	10
6.3	Migration to ETCS Level 3 with Moving Block never delivered	6	6	1	3	7	10	6	10	7	8	8	10	6	6	3	9	5	9	2	10	8	10
6.4	Migration to ETCS Level 3 with Moving Block may take a very long time	7	7	1	3	10	6	9	9	7	7	9	9	7	7	5	4	10	10	7	9	9	10
6.5	Uncertainty about track, train, route systems and the migration sequence	5	5	5	4	7	6	6	6	6	5	3	8	8	8	7	2	8	8	7	8	5	5
Business case																							
7.1	Costs exceed the benefits	8	8	8	4	4	8	7	7	8	7	9	10	3	5	4	9	10	10	7	10	9	10
7.2	Costs understood, benefits less clear and in the future	6	8	8	4	3	8	6	7	8	6	5	7	5	5	7	3	9	10	6	8	7	8
7.3	Unable to define the Units of output at which benefits exceed the costs	7	7	7	4	3	7	6	7	5	5	3	7	3	4	3	8	9	7	4	7	8	8
7.4	Uncertainty about lifetime costs (maintenance and recovery)	7	4	3	5	6	5	6	7	7	5	3	7	6	6	8	8	9	6	3	5	6	10

7.5	Uncertainty about compatibility with next generation of CCS	6	4	3	7	5	5	6	7	4	7	2	7	3	5	5	5	8	9	6	5	10	10
7.6	Uncertainty about what risks (schedule, technical and cost) to build in to project evaluations	6	7	7	4	4	6	5	5	5	5	7	8	5	6	4	4	9	9	3	5	8	8
7.7	Insurers become reluctant to carry risks of solutions	7	6	6	3	7	9	3	6	5	7	5	5	4	6	2	6	2	4	5	7	9	9
7.8	Elapsed time between now and implementation may change business cases													8	8	8	3	8	5	7	7	10	8
7.9	Passengers may not adjust to the different operations													1	1	1	5	2	3	3	6	4	10
7.10	Business case impossible to forecast before implementation													2	6	3	8	8	9	7	9	6	8
Public acceptance																							
8.1	Media/public suspicious of trains that cannot stop in the gap to the next train	7	7	2	5	3	2	8	8	7	8	10	10	1	1	4	4	3	2	4	5	9	6
Safety																							
9.1	Accident during testing undermines confidence	6	9	3	2	4	8	4	10	5	8	1	10	2	6	8	2	3	7	2	5	8	5
9.2	Accident during live operation undermines confidence	3	9	8	6	3	10	2	10	3	10	1	10	1	9	7	2	2	8	1	9	5	10
9.3	Near mIsses during testing	7	8	6	1	5	7	8	6	6	5	1	10	4	5	10	2	3	5	3	6	9	5
9.4	Near misses during operations	5	9	2	6	3	9	2	8	3	9	1	10	3	6	8	3	1	9	2	9	5	10
9.5	Repeated failures not leading to incidents	8	5	6	1	4	9	9	6	7	7	3	8	7	5	5	2	3	5	6	8	7	7