Are Smart Contracts and Blockchains Suitable for Decentralized Railway Control?: Open Review

Michael Kuperberg,*† Daniel Kindler,‡ Sabina Jeschke§

Reviewers: Reviewer A, Reviewer B, Reviewer C, Reviewer D, Reviewer E

Abstract. The final version of the paper "Are Smart Contracts and Blockchains Suitable for Decentralized Railway Control?" can be found in Ledger Vol. 5 (2020) 36-61, DOI 10.5915/LEDGER.2020.158. There were five reviewers involved in the review process, none of whom have requested to waive their anonymity at present, and are thus listed as Reviewers A through E. After initial review by Reviewers A and B, the submission was returned to the authors with feedback for revision (1A). The authors responded (1B) and resubmitted their work. The resubmission was sent to Reviewers B, C, and D, after which the revised submission was again returned to the authors with feedback for further revision (2A). The authors responded (2B) and resubmitted with further revisions. After further review by Reviewers B and E, the editorial decision was made that the revisions made to this point were sufficient, thus ending the peer review process. Author responses are bulleted for clarity.

1A. Review

Reviewer A

Thank you very much for the opportunity to read your paper introducing a blockchain-based prototype implementation for railway control. There is much to like about your paper such as the innovative approach and timely topic. However, I also have several concerns about the current version as I will outline below.

The introduction section needs to be much more focused and structured. Importantly, I would recommend that you start with more background information on the current state of the art,

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and how blockchain, smart contracts etc. may improve the current state. Thus, you need to answer the following questions:

Why is the topic relevant and for whom does it matter?

What do we already know?

What do we not know?

How are you going to address this gap?

With this structure it will be easier to hook the reader from the beginning.

Figure 1 is hard to read and should thus be improved. Maybe you could add some explanatory text directly under the figure. Moreover, what does "some IT building blocks" really mean? What is missing and why do you focus on these building blocks and not others? This needs to be addressed.

You write: "In this paper, we investigate a disruptive approach to train control based on Distributed Ledger Technologies (DLTs) that thoroughly rethinks the involved roles" – what does "disruptive" really mean in this context? Why do you think it is disruptive? Disruptive innovation theory (Christensen et al., 2015; Yu & Hang, 2010), that coined the term, would interpret this differently and probably not talk about disruption in this context. Please clarify in the text and refer to the theory when making "disruption" claims.

The architecture and prototype implementation are interesting. Could you add one or more tables showing how your solution compares to current solutions and other solutions without DLT on several criteria that you mention in the text? This way, readers will see at one glance the advantages and disadvantages of your solution vis-à-vis solutions based on different technologies.

You also need to derive criteria for the comparison mention in my point 4. above in a logical and coherent way. Please also justify why you picked these criteria and not others.

Please also compare different DLT technologies against each other for your prototype: you touch upon this on p. 9 but this needs to be much more systematic to be valuable for readers.

Figure 2 and Figure 4 are again very hard to read and understand – please improve.

I wish you good luck as you continue to work on the manuscript.

References

Yu, D., & Hang, C. C. (2010). A reflective review of disruptive innovation theory. International Journal of Management Reviews, 12(4), 435-452.

Christensen, Clayton M., Michael E. Raynor, and Rory McDonald. "What is disruptive innovation." Harvard Business Review 93.12 (2015): 44-53

Reviewer B

The paper "Are Smart Contracts and Blockchains Suitable for Decentralized Railway Control" describes a decentralized railway control versus the conventional top-down railway control by describing a prototype and resulting simplifications as well as addressing the use of Blockchain as a life cycle approach for condition based monitoring and predictive maintenance. The paper is divided in six chapters: (1) introduction, (2) work objective, scope definition and assumption, (3) solution architecture and employed technologies, (4) the prototype implementation of the Blockchain-based control core, (5) related work and (6) conclusion and future work.

For an academic journal publication, several steps are important

- Academic literature review

- Research questions and hypothesis

- Approach to test hypothesis

- Discussion of insights, further research necessary

While the paper provides interesting insights in setting up a prototype of a decentralized railway control, it does not cover above steps in a detail sufficient for an academic publication.

I therefore reject and would recommend to write the piece as a case study or feasibility study and then to deduct research questions.

1B. Author Responses

Reviewer A

Thank you very much for the opportunity to read your paper introducing a blockchain-based prototype implementation for railway control. There is much to like about your paper such as the innovative approach and timely topic. However, I also have several concerns about the current version as I will outline below.

The introduction section needs to be much more focused and structured. Importantly, I would recommend that you start with more background information on the current state of the art, and how blockchain, smart contracts etc. may improve the current state.

- Answered in the (new) Section 1, the first two paragraphs

Thus, you need to answer the following questions:

Why is the topic relevant and for whom does it matter?

- Section 1 (new)

What do we already know?

- Section 1 (new)

What do we not know?

- Section 1 (new)

How are you going to address this gap?

- Section 1 (new)

With this structure it will be easier to hook the reader from the beginning.

Figure 1 is hard to read and should thus be improved.

- This figure has been redrawn from the scratch, using a different tool

Maybe you could add some explanatory text directly under the figure. Moreover, what does "some IT building blocks" really mean? What is missing and why do you focus on these building blocks and not others?

- This is explained in the text („In reality, there are additional layers" ...) where the figure is introduced.

This needs to be addressed.

- Figure 1 has be redrawn for larger fonts and now includes the IT building blocks which were originally excluded.

You write: "In this paper, we investigate a disruptive approach to train control based on Distributed Ledger Technologies (DLTs) that thoroughly rethinks the involved roles" – what does "disruptive" really mean in this context? Why do you think it is disruptive? Disruptive innovation theory (Christensen et al., 2015; Yu & Hang, 2010), that coined the term, would interpret this differently and probably not talk about disruption in this context. Please clarify in the text and refer to the theory when making "disruption" claims.

- On page 5 (section 2), a new paragraph is dedicated to the response to these questions.

The architecture and prototype implementation are interesting. Could you add one or more tables showing how your solution compares to current solutions and other solutions without DLT on several criteria that you mention in the text? This way, readers will see at one glance the advantages and disadvantages of your solution vis-à-vis solutions based on different technologies.

You also need to derive criteria for the comparison mention in my point 4. above in a logical and coherent way. Please also justify why you picked these criteria and not others.

- There are no solutions that we could currently compare with: there are no other blockchain-based implementations of railway control systems (or any other traffic control systems), and our prototype is not yet mature enough to be compared to the „traditional" centralized control systems, e.g. in terms of performance. Additionally, comparisons between dispatching systems are very complicated because a single decision changes the subsequent course of actions and in general, there is no „ideal solution". Therefore, special metrics have to be defined (e.g. delay minutes weighted by train type), which we would address in future work. Therefore, we have not added any tables.

Please also compare different DLT technologies against each other for your prototype: you touch upon this on p. 9 but this needs to be much more systematic to be valuable for readers.

- A large new list of arguments pro Ethereum has been added to the beginning of the (revised) section 5. Additionally, we have referenced existing publications that compare/survey blockchain platforms. Still, we believe that a full comparison of Ethereum with other blockchain platforms would be outside the scope of this paper, and would also water down the message that the paper tries to convey. We believe that the added text serves the readers well.

Figure 2 and Figure 4 are again very hard to read and understand – please improve.

- Component diagrams have been redmodeled from the scratch and feature larger fonts. In the sequence diagram (Figure 4), fonts have been enlarged for better legibility.

I wish you good luck as you continue to work on the manuscript.

References

Yu, D., & Hang, C. C. (2010). A reflective review of disruptive innovation theory. International Journal of Management Reviews, 12(4), 435-452.

Christensen, Clayton M., Michael E. Raynor, and Rory McDonald. "What is disruptive innovation." Harvard Business Review 93.12 (2015): 44-53

Reviewer B

The paper "Are Smart Contracts and Blockchains Suitable for Decentralized Railway Control" describes a decentralized railway control versus the conventional top-down railway control by describing a prototype and resulting simplifications as well as addressing the use of Blockchain as a life cycle approach for condition based monitoring and predictive maintenance. The paper is divided in six chapters: (1) introduction, (2) work objective, scope definition and assumption, (3) solution architecture and employed technologies, (4) the prototype implementation of the Blockchain-based control core, (5) related work and (6) conclusion and future work.

For an academic journal publication, several steps are important

-      Academic literature review

  - This is included in the section 4 („Related work", now retitled to include „literature review")

    -     Research questions and hypothesis

  - These aspects have been phrased more prominently, and keywords have been placed to make them easier to find in the text - see the first two paragraphs of the (new) section 3

    -     Approach to test hypothesis

  - Separate paragraph in the (new) section 3

    -     Discussion of insights, further research necessary

  - This is covered by section 7 (Conclusion and Future Work), which has been rewritten.

While the paper provides interesting insights in setting up a prototype of a decentralized railway control, it does not cover above steps in a detail sufficient for an academic publication.

I therefore reject and would recommend to write the piece as a case study or feasibility study and then to deduct research questions.

2A. Second Round Review

Reviewer B

Does this paper represent a novel contribution to cryptocurrency or blockchain scholarship?

Yes

If you answered "yes" to the previous question, in one sentence, describe in your own words the novel contribution made by this paper:

The paper aims to evaluate the application of Blockchain technology to railway systems

Is the research framed within its scholarly context and does the paper cite appropriate prior works?

Important references are missing

Please assess the article's level of academic rigor:

Unsatisfactory (better than poor but a long way from excellent)

Please assess the article's quality of presentation:

Unsatisfactory (better than poor but a long way from excellent)

How does the quality of this paper compare to other papers in this field?

Bottom 50%

Please provide your free-form review for the author in this section:

The paper "Are Smart Contracts and Blockchains Suitable for Decentralized Railway Control" was reworked. It describes a decentralized railway control versus the conventional top-down rail-way control by describing a prototype and resulting simplifications as well as addressing the use of Blockchain as a life cycle approach for condition based monitoring and predictive maintenance. The paper is divided in seven chapters: (1) introduction, (2) foundations, (3) work objective and scope, research question, hypothesis and assumption, (4) Related work and literature review, (5) solution architecture and employed technologies, (6) the prototype implementation of the Block-chain-based control core, and (7) conclusion and future work.

For an academic journal publication, several steps are important
- Academic literature review
- Research questions and hypothesis
- Approach to test hypothesis
- Discussion of insights, further research necessary

While the paper has improved, it does not cover above steps in a detail sufficient for an academic publication.

I therefore reject and would recommend to write the piece as a case study or feasibility study and then to deduct research questions. These could then lead to the question of comparing a

central and a decentral approach identifying issues and potential solutions.

Reviewer C

Does this paper represent a novel contribution to cryptocurrency or blockchain scholarship?

Yes

If you answered "yes" to the previous question, in one sentence, describe in your own words the novel contribution made by this paper:

This paper discusses incorporating blockchain directly into the train management system rather than just ticket sales.

Is the research framed within its scholarly context and does the paper cite appropriate prior works?

Yes

Please assess the article's level of academic rigor:

Good (not excellent but a long way from poor)

Please assess the article's quality of presentation:

Good (not excellent but a long way from poor)

How does the quality of this paper compare to other papers in this field?

Top 10%

Please provide your free-form review for the author in this section:

The paper was good, but could be improved. I thought there should be more emphasis on explaining why should blockchain be incorporated into the system, specifically, the downsides of the current system and how the blockchain could provide improvement.

While some advantages are detailed throughout the manuscript, decentralization is usually described as improving " flexibility and cost efficiency." I believe the paper would be improved if a more detailed section was included that would discuss the limitations of the current centralized approach as well as how blockchain would specifically address those limitations. Train control and dispatching could be focused on as that was tested in the prototype. Would safety be improved or be unaffected, for example. How significant would be the proposed cost savings? While the paper may demonstrate that decentralized blockchain applications could be implemented, more justification for a major change in rail management

would be helpful.

Reviewer D

Does this paper represent a novel contribution to cryptocurrency or blockchain scholarship?

Yes

If you answered "yes" to the previous question, in one sentence, describe in your own words the novel contribution made by this paper:

Novel challenging application of blockchain

Is the research framed within its scholarly context and does the paper cite appropriate prior works?

Yes

Please assess the article's level of academic rigor:

Unsatisfactory (better than poor but a long way from excellent)

Please assess the article's quality of presentation:

Unsatisfactory (better than poor but a long way from excellent)

How does the quality of this paper compare to other papers in this field?

Bottom 50%

Please provide your free-form review for the author in this section:

The application of blockchain technology to railway operation is an intriguing and challenging goal, and this paper presents a first experience in this direction.

However, there are several concerns about the presented work.

First of all, railway operation is nowadays distinguishing in a definite way railway operation and traffic management (including decisions on which trains to move), from the actual control of physical devices: the latter has to do with safety issues, while the former, which can be seen as higher level layers over the lower level interlocking and ATP layers, is not concerned about safety, whose guarantee is delegated to the lower levels. This neat distinction is functional to different assignment of criticality to the various functions, in order to minimise the costs due to certification.

This paper proposes to address both aspects through the use of blockchain in order to decentralised the information over the real-time status of the railway operation on one side and of the physical devices on the either side.

While it is rather immediate to see the advantages that blockchain can bring to railway operation, traffic management, and maintenance, by unifying in a single technological layer reservation of routes and accounting of track usage, it is not clear whether and how the actual command and control of physical devices can actually benefit of this unification.

The ability of blockchain to support real-time behaviour and to guarantee the ultra-high safety requirements typical of the railway domain is a real challenge.

Actually, it can be easily imagined a future distributed railway operation system based on blockchain as the proposed one, limited to the traffic management functions, offering to trains route reservation and to operators track usage accounting, but referring to a (traditional) route-based interlocking system to guarantee safety of the operation.

The problem with this paper is that, due to the limited amount of details provided, it is actually not clear whether the presented prototype does address physical device control, or just limits itself to traffic management (route reservation and accounting), basing on the traditional "security/safety/localization" mechanisms inherited by the underlying system.

If the proposal in the paper wants to include the safety-critical functions as well, more evidence should be given to the reader about the experiments done, e.g. giving figures about the real-time response experienced in the prototype, so to be able to, for example, discuss how blockchain technology advances can fill the current performance gap. Also showing in some more details how EN50128/EN50159 guidelines should be addressed in real implementations fo these principles can give the reader more confidence about the actual possible use of blockchain technology as a unifying basic mechanism for all functions.

Otherwise, if this goal was already in the prototype considered unreachable for blockchain technology, due to low performance in real-time operation and/or high costs for safety certification, the authors should clearly express this, and give details about the separation between blockchain-based traffic management functions and underlying safety layers provided by interlocking and\or ATP mechanisms implemented in the prototype.

Minor comments and typos:

page 1 line 3 from bottom "rail control systems" in this part of the article you are not speaking about trains, but rather about generic control systems, so I would remove "rail" form this sentence

page 2 sect. 2 line 3 or even death —> or even passenger death.
last line electronical —> electronic

pag 5 , lines 18 and 19 security —> safety

page 6 lines 28-30 Anticipate sentence "For example…occupied block" before "However … network"
line 28: they —> the are not provided —> is not provided
first line of sect.4 I think that railway operation management, not control, has been addressed in the cited research

page 7 line 9 from bottom: "in an integrated way" Actually, looking inside in a modern CBTC, (as also shown by the international standards about CBTC) you can find a neat distinction between IXL , ATP and ATO subsystems on one side (control) and the ATS subsystem on the other side (management); only the first two are normally rated SIL4. They are integrated, in the sense that they are specifically built, often on a proprietary basis, to optimise the interactions between these subsystems, so that they appear as a single system to their user, but the functions are kept strictly separate.

page 8 line 5 in the law —> by law
line 7 decentral —> decentralized

page 9 line 12: what do you intend by "design for failover" ?
line 21 by "future state" do you intend what before you called "should be" ? So it is rather a "possible future state" or a "required future state".

page 10 line 1 expires —> expired
line 9 security-relevant —> safety-relevant
line 11 what is the "happy path" ?

page 12 5th bullet "security/safety/localization…" so you actually have a layer inherited by the basic control of physical devices related to safety and localization! About security, do you mean that rely on existing basic secure protocols to guarantee security of the blockchain communication exchanges?
last line: what do you mean by "correct position"?

page 15 line 2 Can you give hint to which are the foreseen formal verification approaches, goals and challenges?
line 16 can you give a reference for "sharding"?
line 2 of Sect. 7 The paper does not actually show how traditional railway safety principles are taken into account, since no detail is given at this respect.
line 8 the in the —> in the
line 16; you should give the reason why you think that the systems will be more fault-tolerant

page 16 line 15: side chains, state channels: explain or give a reference
lines 18-20 missing verb

2B. Authors' Response to Second Round Review

Reviewer B

Does this paper represent a novel contribution to cryptocurrency or blockchain scholarship?

Yes

If you answered "yes" to the previous question, in one sentence, describe in your own words the novel contribution made by this paper:

The paper aims to evaluate the application of Blockchain technology to railway systems

Is the research framed within its scholarly context and does the paper cite appropriate prior works?

Important references are missing

- This comment is not precise enough to be addressed (see below); the paper already includes 63 references (up from 47 in the initial submission).

Please assess the article's level of academic rigor:

Unsatisfactory (better than poor but a long way from excellent)

Please assess the article's quality of presentation:

Unsatisfactory (better than poor but a long way from excellent)

How does the quality of this paper compare to other papers in this field?

Bottom 50%

Please provide your free-form review for the author in this section:

The paper "Are Smart Contracts and Blockchains Suitable for Decentralized Railway Control" was reworked. It describes a decentralized railway control versus the conventional top-down rail-way control by describing a prototype and resulting simplifications as well as addressing the use of Blockchain as a life cycle approach for condition based monitoring and predictive maintenance. The paper is divided in seven chapters: (1) introduction, (2) foundations, (3) work objective and scope, research question, hypothesis and assumption, (4) Related work and literature review, (5) solution architecture and employed technologies, (6) the prototype implementation of the Block-chain-based control core, and (7) conclusion and future work.

For an academic journal publication, several steps are important
- Academic literature review
- Research questions and hypothesis

- Approach to test hypothesis
- Discussion of insights, further research necessary

While the paper has improved, it does not cover above steps in a detail sufficient for an academic publication.

- For the authors to improve the paper in the sense of the reviewer, it would be very helpful to have a few precise examples of what is missing. For example, "academic literature review" is included in Section 6 and to the best of our knowledge, we include all relevant related work as of the time of initial submission. Likewise, we formulate a hypothesis and research questions; these have now been separated into separate section for better readability.

I therefore reject and would recommend to write the piece as a case study or feasibility study and then to deduct research questions.

- As clearly stated in the abstract, we "present the case study findings". We have added more structure to research questions; and additional explanation on why we formulate research questions first and perform a case study afterwards.

These could then lead to the question of comparing a central and a decentral approach identifying issues and potential solutions.

- A quantitative comparison as one direction of future work has been added to the last section.

Reviewer C

Does this paper represent a novel contribution to cryptocurrency or blockchain scholarship?

Yes

If you answered "yes" to the previous question, in one sentence, describe in your own words the novel contribution made by this paper:

This paper discusses incorporating blockchain directly into the train management system rather than just ticket sales.

Is the research framed within its scholarly context and does the paper cite appropriate prior works?

Yes

Please assess the article's level of academic rigor:

Good (not excellent but a long way from poor)

Please assess the article's quality of presentation:

Good (not excellent but a long way from poor)

How does the quality of this paper compare to other papers in this field?

Top 10%

Please provide your free-form review for the author in this section:

The paper was good, but could be improved. I thought there should be more emphasis on explaining why should blockchain be incorporated into the system, specifically, the downsides of the current system and how the blockchain could provide improvement.

- New explanations have been added (see papers sections highlighted in yellow).

While some advantages are detailed throughout the manuscript, decentralization is usually described as improving " flexibility and cost efficiency."

- A more concise explanation has been added.

I believe the paper would be improved if a more detailed section was included that would discuss the limitations of the current centralized approach as well as how blockchain would specifically address those limitations.

- This has been addressed.

Train control and dispatching could be focused on as that was tested in the prototype. Would safety be improved or be unaffected, for example.

- Section on Safety has been added.

How significant would be the proposed cost savings?

- A paragraph on this question has been added to the last section.

While the paper may demonstrate that decentralized blockchain applications could be implemented, more justification for a major change in rail management would be helpful.

- Several new paragraphs have been added with regard to this question.

Reviewer D

Does this paper represent a novel contribution to cryptocurrency or blockchain scholarship?

Yes

If you answered "yes" to the previous question, in one sentence, describe in your own words the novel contribution made by this paper:

Novel challenging application of blockchain

Is the research framed within its scholarly context and does the paper cite appropriate prior works?

Yes

Please assess the article's level of academic rigor:

Unsatisfactory (better than poor but a long way from excellent)

Please assess the article's quality of presentation:

Unsatisfactory (better than poor but a long way from excellent)

How does the quality of this paper compare to other papers in this field?

Bottom 50%

Please provide your free-form review for the author in this section:

The application of blockchain technology to railway operation is an intriguing and challenging goal, and this paper presents a first experience in this direction.

However, there are several concerns about the presented work.

First of all, railway operation is nowadays distinguishing in a definite way railway operation and traffic management (including decisions on which trains to move), from the actual control of physical devices: the latter has to do with safety issues, while the former, which can be seen as higher level layers over the lower level interlocking and ATP layers, is not concerned about safety, whose guarantee is delegated to the lower levels.

- The distinction between dispatching and ERTMS has already been present in the submitted version. In the current revision, additional text has been added to highlight the differences between the two layers. Additionally, layering is now visually present: a new, additional illustration (new Figure 1) has been introduced. ATP as a term is now also explained.

This neat distinction is functional to different assignment of criticality to the various functions, in order to minimise the costs due to certification.

- Certification has now been added, too.

This paper proposes to address both aspects through the use of blockchain in order to decentralised the information over the real-time status of the railway operation on one side and of the physical devices on the either side.

While it is rather immediate to see the advantages that blockchain can bring to railway operation, traffic management, and maintenance, by unifying in a single technological layer reservation of routes and accounting of track usage, it is not clear whether and how the actual command and control of physical devices can actually benefit of this unification.

- For this paper, it's the efficiency of the overall system.

The ability of blockchain to support real-time behaviour and to guarantee the ultra-high safety requirements typical of the railway domain is a real challenge.

- Yes, and we do mention that

Actually, it can be easily imagined a future distributed railway operation system based on blockchain as the proposed one, limited to the traffic management functions, offering to trains route reservation and to operators track usage accounting, but referring to a (traditional) route-based interlocking system to guarantee safety of the operation.

The problem with this paper is that, due to the limited amount of details provided, it is actually not clear whether the presented prototype does address physical device control,

- A new paragraph has been added to the "The Prototype Implementation" section which explains this in great detail.

or just limits itself to traffic management (route reservation and accounting), basing on the traditional "security/safety/localization" mechanisms inherited by the underlying system.

- Our system includes <u>both</u> the traffic management and the "live" control (dispatching), while indeed utilizing the safety and localization mechanisms. Our approach is designed to interact with newer localization mechanisms, too.

If the proposal in the paper wants to include the safety-critical functions as well, more evidence should be given to the reader about the experiments done, e.g. giving figures about the real-time response experienced in the prototype, so to be able to, for example, discuss how blockchain technology advances can fill the current performance gap.

- Numbers from the prototypic implementation would be misleadingly discouraging, as we neither tried to select the fastest blockchain implementation nor did we optimize the prototypic application for performance on its own.

Also showing in some more details how EN50128/EN50159 guidelines should be addressed in real implementations fo these principles can give the reader more confidence about the actual possible use of blockchain technology as a unifying basic mechanism for all functions.

- This is definitely out of scope for the current paper.

Otherwise, if this goal was already in the prototype considered unreachable for blockchain technology, due to low performance in real-time operation and/or high costs for safety certification, the authors should clearly express this, and give details about the separation between blockchain-based traffic management functions and underlying safety layers provided by interlocking and\or ATP mechanisms implemented in the prototype.

- As stated above, it is too early to discuss performance here.

Minor comments and typos:

page 1 line 3 from bottom "rail control systems" in this part of the article you are not speaking about trains, but rather about generic control systems, so I would remove "rail" form this sentence

- Done

page 2 sect. 2 line 3 or even death —> or even passenger death.

- No, it's operator's death (now added, despite redundancy)

last line electronical —> electronic

- Done (also at another position)

pag 5 , lines 18 and 19 security —> safety

- Done

page 6 lines 28-30 Anticipate sentence "For example…occupied block" before "However … network"

- Done. This is the last two paragraphs between Related Work.

line 28: they —> the are not provided —> is not provided

- Done

first line of sect.4 I think that railway operation management, not control, has been addressed in the cited research

- Done

page 7 line 9 from bottom:

- This is the paragraph with „turnkey" in it

"in an integrated way" Actually, looking inside in a modern CBTC, (as also shown by the international standards about CBTC) you can find a neat distinction between IXL , ATP and ATO subsystems on one side (control) and the ATS subsystem on the other side (management); only the first two are normally rated SIL4. They are integrated, in the sense that they are specifically built, often on a proprietary basis, to optimise the interactions between these subsystems, so that they appear as a single system to their user, but the functions are kept strictly separate.

- Replaced „central" through "modularized" in the paper.

page 8 line 5 in the law —> by law

- Done

line 7 decentral —> decentralized

- Done (throughout the document)

page 9 line 12: what do you intend by "design for failover" ?

- Explanation added

line 21 by "future state" do you intend what before you called "should be" ? So it is rather a "possible future state" or a "required future state".

- Done

page 10 line 1 expires —> expired

- Done

line 9 security-relevant —> safety-relevant

- Done

line 11 what is the "happy path" ?

- Done

page 12 5th bullet "security/safety/localization…" so you actually have a layer inherited by the basic control of physical devices related to safety and localization!

- Done (see text marked in yellow)

About security, do you mean that rely on existing basic secure protocols to guarantee security of the blockchain communication exchanges?

- We no longer mention security here (but yes, we do employ the security of the blockchain implementation)

last line: what do you mean by "correct position"?

- Added section on „converging" and "diverging" directions of travelling.

page 15 line 2 Can you give hint to which are the foreseen formal verification approaches, goals and challenges?

- I think this is outside the scope of the paper, and would be rather speculative.

line 16 can you give a reference for "sharding"?

- Done

line 2 of Sect. 7 The paper does not actually show how traditional railway safety principles are taken into account, since no detail is given at this respect.

- Rephrased

line 8 the in the —> in the

- Done

line 16; you should give the reason why you think that the systems will be more fault-tolerant

- Added „through replication and failover.

page 16 line 15: side chains, state channels: explain or give a reference

- Done

lines 18-20 missing verb

- Done