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Risk-Assessment

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The following report describes the methodology and results of a conducted Risk-Assessment by BASF regarding a newly developed railway system. To conduct the Risk-Assessment, BASF was supported by the Technical University of Berlin; Faculty V for Mechanical Engineering and Transport Systems, Chair of Land and Sea Transport Systems, Chair of Rail Vehicles. This Risk-Assessment report includes the findings of scientific investigations conducted by the Technical University of Berlin. Accordingly, the presented report is a joint document by BASF and the Technical University of Berlin, which approved the depiction and interpretation of their findings. This publication summarizes the Risk-Assessment approach and its findings, based on the report submitted for the independent assessment. Due to compliance, patent and concealment agreements, distinctive information is removed.

Abstract

BASF introduced a new system to the railway system, consisting of high-volume BASF Class Tank-Containers and innovative container carrying wagons. Although a significance assessment resulted in a not significant change, BASF voluntarily offered to conduct an entire Risk Assessment in accordance with the European Regulation for Common Safety Methods. Accordingly, several hazards are identified for the new system within the railway system and elaborated following the Common Safety Method. Each identified hazard is investigated following a suitable risk acceptance principle. Respectively, various scientific investigations are conducted supported by the Technical University of Berlin. Eventually, all identified hazards for the already existing system, which is already in use for more than two years, can be classified as broadly acceptable. Furthermore, for distinct hazards it can be stated, that the new system reaches a higher safety level as its conventional counterparts. However, to further improve the overall safety level of the railway system, BASF introduces additional safety measures accordingly.

Author

Marc Frederic Schröder, M. Sc.

Project Engineer, Railcar- and Tank-Workshop

+49 621 60-59861

marc-frederic.schroeder@basf.com

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Abbreviations

B-TC	BASF Class Tank-Container
iCTW	innovative Container Carrying Wagon
CCW	Container Carrying Wagon
RTC	Rail Tank Car
TC	Tank-Container
AGV	Automated Guided Vehicle
OTIF	Inter-Governmental Organization for International Carriage by Rail
RA	Risk-Assessment
TUB	Technical University of Berlin
RAP	Risk Acceptance Principle
VPI	Verband der Güterwagenhalter in Deutschland E.V.

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1. Introduction

BASF Class Tank-Container (B-TC) combine the best of two worlds. Together with innovative container carrying wagons (iCTW), the new system maintains a similar payload as classic rail tank wagons, while being as flexible as intermodal tank-containers.

The rail and storage optimized B-TC were developed in collaboration of BASF with a European manufacturer and have been approved in 2015, fulfilling all regulatory requirements. Weighing up to 75 tons, a length of 45' and with a volume of 63.000 liters, B-TC approximately double the capacity and size of intermodal tank-containers.

The particularly light and quiet iCTW have been especially designed for the usage of the B-TC. Following the TIS 5L initiative, the iCTW has been developed respectively by a European manufacturer, in collaboration with a freight wagon system provider and BASF.

To enable the flexibility of the new system, while maintaining the payload and economic advantages of classical rail transportation, it is accompanied by two further logistics innovations. Whereas on the main run B-TC are carried on iCTW, the first and last mile transport is realized by Automated Guided Vehicles (AGV). By saving up to four days in transportation time, rail transportation benefits from autonomous road driving technologies.

The interface between rail and AGV transports is a fully automated tank container depot with a capacity of 2.000 TEU. In this specifically build depot, B-TC are stacked up to six high in a space-saving, quickly available and cost-effective manner.

By using B-TC, iCTW, AGV and the fully automated depot, logistics become faster, more flexible and significantly more economic. Furthermore, it is an incentive to relocate more goods onto rails.

Disrupting the conventional rail transport of chemical goods by classical rail tank cars, the newly developed system aroused great interest in the chemical industry, transportation sector, as well as regulatory organizations and agencies.

Being topic of the 8^{th} Session of the RID Committee of Experts' standing working group (Utrecht, 24^{th} & 25^{th} of November 2017), the Inter-Governmental Organization for International Carriage by Rail (OTIF) requested more details and information of the new system. Following this request, BASF promised to conduct a voluntary Risk-Assessment (RA) in accordance with the common safety method for risk evaluation and assessment, which is established in the European regulation (EU) 402/2013.

As part of this voluntary RA in accordance with the EU CSM Directive ((EU) 402/2013), BASF compared the new system consisting of the B-TC and iCTW, to two existing rail freight transportation systems. The conventional rail tank car (RTC) and the intermodal tank container (TC) traffic are considered as reference systems.

Following the risk management process, various scientific approaches such as measurements, simulations and calculations were carried out in collaboration with the Technical University of Berlin (TUB).

Based on identified hazards by BASF and TUB rail experts, the scientific approaches to assess the safety level of the new system included; short- and long-term driving tests, impact-tests, data gathering during driving and impact-tests for multi-body and finite element simulations.

The aim of the RA was to determine the safety level of the new system, in comparison to the reference systems. Furthermore, the gained results and insights are obtained to assess if regulations for the transport of hazardous goods should be adjusted.

This report presents the conducted RA in accordance with the CSM regulative, following the general principles and obligations, established in (EU) 402/2013 Annex 1. It is submitted to Bureau Veritas France, the assessment body, for an independent assessment.

2. Significance Assessment

The CSM Directive ((EU) 402/2013) for risk evaluation and assessment applies to any change in the railway system. Such changes may be of technical, operational or organizational nature. Regarding the new B-TC and iCTW introduced by BASF and certain European manufacturers, a change to the railway system is given by means of derivates of the commonly used TC and container carrying wagons (CCW).

According to Article 4.1 of the CSM Directive ((EU) 402/2013), these changes are subject to a significance assessment to assess possible safety relevant influences on the railway system. Conducted by 'the proposer' BASF, the following chapter summarizes the respective results, which were elaborated by an expert committee of BASF SE employees.

2.1 Scope of Significance Assessment

The new system under investigation consist of the B-TC and the iCTW. However, certain components and technical specifications, which can have an impact on safety, of the B-TC and iCTW are taken into consideration. These subsystems can be characterized as improvement, derivates or new developments and represent changes to the railway system in accordance with the CSM Directive ((EU) 402/2013). Table 1 illustrates the components and specifications of the B-TC and iCTW under investigation. To determine the significance of the components, specifications, the sub-systems and the overall system, their impact on safety is elaborated in relation to their conventional counterparts and typical hazards for TC in the railway system.

BASF Class Tank-Container (B-TC)	
Size & Volume	B-TC have a significantly larger size and volume compared to conventional tank-containers. BT-C with a length of 45' and volume of 63m³ (52' and 73,5 m³) versus 20' TC with a length of up to 26' and volume in between 20m³ to 36m³.
Weight	Through its optimized wall thickness and material choice, the gross weight of the B-TC was reduced to around 7,5 t. Conventional tank-containers with half the capacity have a weight of around 4 tons.
Structure	The B-TC are self-supporting, whereas conventional TC have a steel frame to support the structure, or are self-supported as well. Therefore, increased tank diameters can be realized to gain more capacity, while reducing the gross-weight simultaneously.
Corner Castings	The B-TC Corner Castings are made from high-strength steel and reinforced to compensate the increased weight.

Innovative Container Carrying Wagon (iCTW)	
Weight	iCTW are payload optimized and are more than 1.000 kg lighter than comparable wagons.
Brake System	45' iCTW are equipped with low noise, low friction disk brakes – aiming for a significant noise reduction and increased mileage.
Frame	Being both optimized for a higher payload and noise reduction, the design features of an iCTW differ from conventional carrying wagons.
Spigots	To compensate the increased payload, the spigots have an increased cross section and are casted from a material of higher mechanical strength (i.e. G24Mn6+Qt1). Spigots of conventional CCW have a significantly smaller cross section and are casted from a material of an inferior material strength.
Buffers	The iCTW are equipped with buffers having a 150 mm lifting, compared to conventional buffers with a lift of 105 mm. Therefore, the iCTW can be used on shunting humps.
System (B-TC & iCTW)	
Flexibility	The iCTW or B-TC can be used/stored/maintained/transported separately compared to conventional Tank-Wagons. An increased efficiency in logistics processes is enabled.
Storage	As conventional Tank-Wagons are not allowed to "store" chemical/dangerous goods. The B-TC system enables the storage in an appropriate depot.
Life-Cycle-Opt.	The whole system is Life-Cycle-Optimized, meaning that all components are designed for more flexible usage and fast component changes.
Logistics-Opt.	Through the usage of telematic-systems, all components can be tracked, traced and innovative approaches as predictive maintenance can be realized.

Table 1: B-TC & iCTW Components under investigation of SA

2.2 Significance Assessment Process

Based on the given criteria given in Article 4.2 (a) – (e) ((EU) 402/2013), the significance assessment is conducted separately for the B-TC and the iCTW, as well as for the combination of both, where the results of the previous separated assessments are combined, and associated risks are examined.

2.3 Results Significance Assessment of the sub-system B-TC

The proposer is confident that the sub-system 'BASF Class Tank-Container' is not a significant change, as all related risks can be controlled to an acceptable level. Hereafter, the different criteria of the Article 4.2 ((EU) 402/2013) are discussed and elaborated.

Failure Consequence – A failure is not expected under regular circumstances in the railway system. The B-TC were designed according to compulsory regulations as ADR & RID, CSC and UIC. Approval tests according to different norms and regulations ensure structural integrity, which also undergirds the wall-thickness. As for conventional TC and RTC as well, a credible worst-case scenario in the event of failure could lead to not excludable hazards for humans and the environment.

Novelty – The B-TC were developed by experts with knowledge in the design and regulations applicable for TC. The technical construction, manufacturing and approval followed official regulations regarding TC. Whereas the size and volume are new to moveable TC, similar amounts of dangerous goods per loading-unit are transported in classical RTC or on conventional CCW with TC in the railway system for decades. TC of this size are new to the railway system, as well as to the proposer. However, there are no additional regulations or instructions required, as the B-TC are handled as conventional TC.

Complexity – The design and manufacturing of the B-TC is based on existing regulations and manufacturing processes, using already existing parts and assemblies. Furthermore, B-TC can be used in the conventional railway system, where no changes need to be made. [Rating = 0]

Monitoring – B-TC are regularly inspected and constantly monitored, following official regulations for TC. Due to several safety measures and regulations, the condition of a B-TC is more transparent and current as the condition of a conventional TC and RTC.

Reversibility – Reversibility is always given, as conventional TC or RTC can used to transport hazardous goods.

Additionality – B-TC are based on state-of-the-art TC designs, which are used throughout in the railway and transportation system. To ensure the usability and safety, critical components as the overall structure are reinforced and especially designed for larger forces occurring during transportation and handling. These improvements would increase the overall safety of TC as well.

2.4 Results Significance Assessment of the sub-system iCTW

The proposer is confident that the sub-system 'innovative container carrying wagon' is not a significant change, as all related risks can be controlled to an acceptable level. Hereafter, the different criteria of the Article 4.2 ((EU) 402/2013) are discussed and elaborated.

Failure Consequence – A failure is not expected under regular circumstances in the railway system. The iCTW were designed according to applicable regulations. Approval tests according to different norms and regulations ensure structural integrity. As for conventional container carrying wagons for TC with chemical goods, a credible worst-case scenario in the event of failure could lead to not excludable hazards for humans and the environment.

Novelty – The iCTW were developed by experts with knowledge in the design and regulations applicable for container carrying wagons. The technical construction, manufacturing and approval followed official regulations regarding rail wagons. Form and function of the rail car follow recent developments in the design of container wagons. Furthermore, an iCTW can be used for conventional TC as well.

Complexity – The design and manufacturing of the iCTW is based on existing regulations and manufacturing processes, using already existing parts and assemblies. Furthermore, iCTW can be used in the conventional railway system, where no changes need to be made.

Monitoring – iCTW are regularly inspected and constantly monitored, following official regulations for railway vehicles.

Reversibility – Reversibility is always given, as conventional wagons can used to transport TC with hazardous goods.

Additionality – The iCTW design and production followed recent developments, using disk-brakes and light-weight constructions. These developments are well tested and approved, indicating no additional hazards.

2.5 Results Significance Assessment of the new system (B-TC & iCTW)

The proposer is confident that the new system consisting of 'BASF Class Tank-Container' and 'innovative container carrying wagon' is not a significant change, as all related risks can be controlled to an acceptable level. Hereafter, the different criteria of the Article 4.2 ((EU) 402/2013) are discussed and elaborated.

Failure Consequence – A failure is not expected under regular circumstances in the railway system. Both sub-systems were designed according to applicable regulations. Approval tests according to different norms and regulations ensure structural integrity. As for conventional container carrying wagons for TC with chemical goods or in classic RTC, a credible worst-case scenario in the event of failure could lead to not excludable hazards for humans and the environment. However, improved safety relevant components as spigots and corner-castings rather increase the overall safety level.

Novelty – Both sub-systems were developed by experts with knowledge in the design and regulations applicable for the respective sub-system. The technical construction, manufacturing and approval followed official regulations, whereas both have been approved by officials. Although being new to the railway sector, as well as to the proposer, the new system is handled as the conventional TC transport on container carrying wagons.

Complexity – The design and manufacturing of both systems is based on existing regulations and manufacturing processes, using already existing parts and assemblies. The whole system can be used in the conventional railway system, where no changes need to be made. Both sub-systems are derivates and advancements of their conventional counterparts.

Monitoring – Both systems are regularly inspected and constantly monitored, following official regulations for railway vehicles and moveable tanks.

Reversibility – Reversibility is always given, as conventional systems as TC on container carrying wagons or RTC can be used to transport hazardous goods.

Additionality – The iCTW design and production followed recent developments, using disk-brakes and light-weight constructions. These developments are well tested and approved, indicating no additional hazards.

2.6 Significance Assessment Conclusion

Regarding the assessed criteria for both sub-systems and the system as one, the proposer is confident that all associable risks can be controlled by an acceptable level. Typical hazards in the transportation of hazardous goods are controlled by intensive regulations, which the new system is following throughout. Furthermore, measurements to control associable risks are already implemented by means of especially designed safety features in both sub-systems, as reinforced and high-strength corner castings or spigots. Therefore, the proposer concludes, that the system under assessment does not represent a significant change.

Although being assessed as not significant, BASF voluntarily offered to conduct an entire Risk Assessment according to the CSM Directive ((EU) 402/2013), including a throughout risk analysis with hazard identification, evaluation and safety measurements. The following chapters describe the respective risk assessment.

3. Safety Plan

The following chapter elaborates the implementation of the RA in accordance with the CSM Directive ((EU) 402/2013). It is giving further background information to the subject under investigation, introduces involved parties, and describes in general the approaches undertaken for the system definition, hazard identification and classification, risk analysis and evaluation, hazard management, deliverables, and independent assessment.

The objective of the conducted RA is to determine the safety level of the new system, in comparison with the conventional systems of TC and RTC. However, the handling of the B-TC in terminals, as well as the transport via special vehicles is not investigated within this on rail operations focused RA.

3.1 Background Information to the new system

As already described in the introduction, the system under investigation of this RA is the combination of the 'BASF Class Tank-Container' and 'innovative Container Carrying Wagon'. Both systems have been approved by authorities and are in use without safety relevant incidents for more than two years. The combination of the flexibility of TC and the capacity of classical rail tank cars, enables BASF to optimize their logistics, as well as to relocate more transports from road to rail.

B-TC have been developed by the Belgian manufacturer 'Van Hool', as well as by the French company 'Magyar SMS', in collaboration with technical and operational experts of BASF respectively. Both companies have extensive expert knowledge in the development of moveable tanks for several purposes, as well as their manufacturing. With a high vertical range of manufacturing, both companies ensure a high quality of their products and a constant exchange with BASF lead to a product, optimized for the needs and requirements of the transport of liquid chemical goods.

The iCTW have been developed in collaboration by BASF, Wascosa and Tatravagonka. Being an internationally acting provider of freight wagon systems, Wascosa (Suisse) has an extensive knowledge in technical and operational aspects of wagons. Constantly pushing the development of new solutions for the transport of hazardous goods via rail, Wascosa provided crucial input in the development of the iCTW. Furthermore, a significant amount of the used iCTW are rented to BASF by Wascosa. Tatravagonka (Slovakia), is a well-known manufacturer of rail freight cars with a production share of around 20% in Europe. Having an extensive knowledge in the development and manufacturing of rail freight cars for different purposes, Tatravagonka designed and built the iCTW especially for the transport of B-TC.

BASF is currently the only operator and user of the new system. However, offering the described optimization possibilities, it is expected that further companies from different industry sectors will invest in the new system. Similar TC and wagons are already in development by different manufactures and different companies from the chemical industry implied their interest in the new system.

The new system is further accompanied by automated guided vehicles (AGV) to transport the B-TC within the Ludwigshafen site of BASF. Following a transponder network, seven autonomous vehicles can travel in between pedestrians, cars, trucks and rail-vehicles while being surveilled by a control center, which has access to the sensors and cameras of the AGV.

The interface between rail and road transportation of the B-TC is a fully automated TC depot with a capacity of 2.000 TEU. Two portal cranes can stack the B-TC up to six-high, before they are loaded or unloaded on to an iCTW or AGV. Three rail-tracks allow the clearance of trains up to 500 m, whereas in eight loading-bays AGV or conventional trucks can be loaded and unloaded.

3.2 Involved parties in the Risk Assessment

This sub-chapter gives a brief introduction of the involved parties of the RA and their associated functions. Table 3 illustrates the roles of each involved party according to the CSM Directive, as well as of organizational and supervisory roles.

BASF SE – Being the proposer of the new system, BASF is responsible for the conduction of the RA and acts as project lead, ensuring that all actions taken are in accordance with the CSM Directive. BASF is represented by railway experts, which have been involved in the design, production and implementation of the new system, as well as in BASF's ECM and Railway Undertaking. Furthermore, experts from the transportation safety department are involved. BASF is also providing the equipment under investigation (i.e. B.TC and iCTW).

TU Berlin – The Institute of Land and Sea Transportation Systems, Chair of Rail Vehicles represented by Prof. Dr.-Ing. M. Hecht and his research assistants support the RA on behalf of BASF. Several research assistants are involved in the project, conducting different work-packages. The support of the TU Berlin experts is divided into six work-packages to investigate, elaborate and assess identified hazards.

Bureau Veritas Exploitation – The European Centre of Technique of Bureau Veritas interacts as Assessment Body in accordance with the CSM Directive.

Manufacturers (i.e. Magyar SMS, Van Hool, Wascosa/Tatravagonka) – The manufacturers provide technical documents, support analysis of the TU Berlin and support the different stages of the RA.

Sounding Board – For supervisory aspects a sounding board is implemented. Representors of different stakeholders, such as the BMVI, BAM and others are constantly informed about the ongoing RA.

3.3 RA approaches

3.3.1 System Definition

As this RA determines the safety level of an already existing system, the System Definition describes the sub-systems B-TC and iCTW under investigation. Therefore, technical specifications, handling information are presented to provide an understanding of the systems' scope, interfaces and boundaries.

3.3.2 Hazard Identification and Classification

Hazards are identified and classified by railway experts of BASF and TU Berlin to provide a comprehensive and complete list of all reasonably foreseeable hazards.. The identification process is iterative, meaning that it is constantly reviewed as more information becomes available. Potential hazards are identified, discussed and classified in several personal or virtual meetings between the involved parties.

3.3.3 Risk Analysis and Evaluation

Based on the identified hazards, the system under investigation is analyzed following the risk acceptance principles. In this RA the principle 'Application of codes of practice', as well 'Comparison with reference system(s)' are deployed. Applying the first risk acceptance principle, the new system is evaluated based on existing regulations, permissions, as well as technical and constructional details. By combing the two principles, the new system is compared to the conventional system of TC and RTC on a paper based and computational basis. Certain hazards are further elaborated by direct comparison of the different systems in terms of simulations, as well as driving and impact-tests. The conducted work-packages are further described and illustrated in the respective risk analyses and evaluations.

3.3.4 Hazard Management

For each identified, analyzed and evaluated hazard, appropriate measurements to control risks and to ensure risks are acceptable are introduced, by providing demonstrable evidence that each hazard is met by respective safety measurements.

3.3.5 Program of activities and timescales

Initialized by BASF the RA is conducted between February 2018 and August 2019. All related activities such as meetings and workshops are organized by BASF.

3.3.6 Independent Assessment

'Bureau Veritas Exploitations' is the appointed assessment body (AsBo) and the RA-Report is delivered in September.

4. System Definition

The following chapter describes the system under investigation of the RA, consisting of the BASF Class Tank-Container and innovative Container Carrying Wagon. Both sub-systems are introduced taking technical, organizational as well as operational aspects into account. Furthermore, the systems boundaries and environment are described, as well as physical and functional interfaces. Finally, existing safety measurements are presented and assumption defining the limits of the conducted RA are introduced. Figure 1 exemplarily illustrates a 45' B-TC by Van Hool on a 45' and 52' iCTW.

Figure 1: 45' Van Hool B-TC on 45' & 52' iCTW

As this RA engages with an already existing system, it is introduced as it is deployed in actual operations. Therefore, the system definition of this RA is no iterative process. However, in the final chapter of this report, further possible safety improvement measurements will be presented.

4.1 System objective

The purpose of the system under investigation is to optimize the logistics of BASF, whereas the transport of liquid bulk goods is clearly in focus. Eventually, conventional rail tank cars will be replaced by B-TC, which are transported on iCTW outside of BASF sites and AGVs within. Besides economic objectives, also operational objectives are pursued. The new system is as flexible as standard TC, whereas is has comparable capacities of classical RTC – ultimately reducing turnover times significantly and increasing efficiency. By this, rail transports gain competitive advantage and the modal split of rail transportation can benefit, eventually leading to a reduction of CO_2-Emissions.

The new system is a technical change within the railway system, although it is handled as conventional transports of the combined transport. Operational and organizational changes are only existing for BASF and are not considered within this RA.

4.2 System functions and elements

BASF utilizes different variations of B-TC. The used variation is depending on the transported product and its respective requirements, which are defined by the RID-regulation such as the Tank-Code, as well as solely product specific aspects as density and needed capacity. As different lengths of B-TC require respective length variations of iCTWs, they are available in sizes of 45', 48', 52' and 54'.

In this RA the 'standard' L4BH B-TC with a volume of 63 m³ is the sub-system under investigation, accompanied by the subsystem iCTW and its 45' and 52' versions. This is accounted for, as the general structure of the B-TC, as well as for the iCTW, is analogous for its different versions, and as the already named B-TC version under investigation is the most frequent. Both sub-systems will be respectively presented in the following sub-chapters.

4.2.1 BASF Class Tank-Container

One sub-system under investigation is the BASF Class Tank-Container. Precisely, the standard L4BH Version with a length of 45' and a capacity of 63m³, which is either developed and manufactured by Van Hool, or Magyar. Both B-TC are investigated in this RA, as they can be distinguished in certain technical aspects, which can have specific repercussions on the safety level in comparison with conventional TC and RTC.

In general, both variations are produced to transport liquid chemicals according to the Tank-Code. Whereas the regulations for TC are followed for approvals, namely CSC and RID, for the general structure (i.e. frame and vessel design), the B-TC are equipped with several attachments, which are more familiar to traditional RTC. Table 2 summarizes the general technical specifications of both B-TC under investigation. The B-TC conform to the provision of the EN 14025 code, as well as chapter 6.8 of the ADR/RID.

	Van Hool	Magyar
Tank-Code	L4BH	
MAWP / Test pressure [bar]	3 / 4,5	
Capacity	63.000 L	
Tare weight [kg]	7.760	7.950

Dimension (L x W x H) [mm]	13.716 x 2.550 x 2.700	
Design Temperature	-40°C / 130°C	
Corner Casting Position	40’	
Stackability	1 + 5	
Vacuum rings	15	7
Shell Material	1.4402 / 316 L	
Wall-Thickness Vessel [mm]	3,4	4,5
Wall-Thickness Heads [mm]	7,9	5,65
Insulation	100 mm	
Heating	6 bar steam	

Table 2: Technical Specifications Van Hool and Magyar B-TC

The B-TC of both manufacturers are self-supporting and do not have baffles. To ensure a discharge without residues, they have an inclination of around 0,1° in the direction of the bottom discharge. Equipped with reinforcements against vacuum risks and for structural integrit, in accordance with RID 4.3.2.3.2, the B-TC are further designed and constructed against over rolling, which is ensured by the vacuum rings and the exposed frame design.

Manufactured from stainless steel, 1.4402, the B-TC vessels follow the requirements for the minimum wall-thickness, which is exceeded by both. The stainless steel 1.4402 (AISI 316L) is characterized as particular resistant against corrosion through acids and is especially suited for applications in the chemical industry. Furthermore, it is eminently weldable, enabling a high-quality and effective production line. The frames of the B-TCs are manufactured from different stainless-steels. Especially stressed parts of the frame are made from high-strength structural steel with extremely consistent properties as duplex steels. Therefore, the B-TC can be stacked up to six high and do not require additional beams to support the self-supporting structure of the vessel. Duplex-steels have a chromium content between 24 and 27%, making them significantly solid and more resistant to corrosion, while being more difficult to machine work than conventional stainless-steels.

4.2.2 Innovative Container Carrying Wagon

The iCTW is an intermodal container carrying wagon, fulfilling the requirements according to TSI WAG and NOI, ERRI recommendations, EN standards, applicable UIC leaflets and the agreement about mutual use of freight wagons in the intermodal transport AVV.

Being developed for the transportation of B-TC, the iCTW are optimized for the respective requirements as increased length of loaded units, payload, as well as the 5L initiative. Table 3 summarizes the technical specifications of the 45’ and 52’ version under investigation.

Technical Specification	45’ iCTW	52’ iCTW
Type	Sgmmnss	
Tare weight	16,5 t	
Payload (D)	73,5 t	
Max. axle load	22,5 t	
Max velocity (S)	100 km/h	
Length over buffer	15.145 mm	17.350 mm
Loading length	13.815 mm	16.020 mm
Distance of boogie centres	10.185 mm	11.920 mm
Height of buffer	1.025 mm	
Loading level	1.105 mm	
Bogie	TVP NG-DBS (Y25-Lsso-D)	Y25 Lsi(f)-C-K
Wheelsets	RI 702	BA 303
Brake type	Disc	Compact CFCB
Brake pads	Becorit BM41NT (590 x 110)	C 810 Bgu (2 x 250)
Air brake	Knorr KE-GP-A (D)	Knorr KE-GP-A (K)
Buffers	Long-stroke (150 mm)	
Drawgear	1000 kN	
Range of use	TEN G1, GE	
Spigots (40’ Position)	Reinforced / fixed	Reinforced / moveable
Shunting Hump	F-II, allowed (F-I) as equipped with long-stroke buffers and reinforced spigots	
Min. Radius (convoy)	150 m	
Min. Radius (single)	75 m	

Table 3: Technical Specifications 45' & 52' iCTW

Although being classified into the F-II category in accordance with EN 12633-2, reinforced spigots from high-strength material (i.e. G24Mn6+Qt1) and a larger cross-section in accordance with UIC 517-4 which withstand longitudinal accelerations of up to 2,7 g, in combination with long-stroke buffers with a stroke of 150 mm enable the iCTW to be used at shunting humps, which is tested, documented and confirmed by the manufacturer.

To optimize the payload of the iCTW, the car body is weight optimized by reducing the amount of needed material while maintaining structural integrity and fulfilling the strength requirements of TSI WAG and EN 12663-2. The frame is a welded steel construction, consisting of two I-Profile side members which are connected by cross members. All dynamically strained parts are made from materials in accordance with EN 10025-2 and EN 10025-3. In accordance with the “5L-Intiative” the iCTWs frame is overlapping the boogies to reduce noise.

4.3 System boundaries

The new system can be used across the European rail infrastructure as conventional intermodal transport units, fulfilling all applicable requirements. Being approved for the G1-Profile, as well as for all rail sections, only load limits in combination with applicable regulations such as the filling degree for TC need to be considered by Railway undertakings and the loader.

However, the handling of the B-TC themselves is limited by the available infrastructure. With a gross weight of up to 75 tons, loaded B-TC can only be handled by suitable terminals. Furthermore, loaded B-TC can only be transported on road by specific vehicles such as the already mentioned AGV. Nevertheless, empty B-TC can be handled by conventional terminals with suitable cranes and can be transported on road by suitable semitrailers.

Currently, only the BASF site in Ludwigshafen is equipped with a respective terminal (i.e the TCL) and suitable road transport vehicles (i.e. AGV). Therefore, both systems are only separated here. Outside of the site, the iCTW and B-TC remain together, where they can be handled basically as conventional rail tank cars. However, a new network of terminals in Europe, able to handle containers up to 75 tons is planned and partially under construction already. Also, AGV road access approvals for selected public roads in Germany are expected within this year. Therefore, the new 75 ton B-TCs form an intermodal system and represents a new segment in this domain.

Figure 9 illustrates the new systems environment, including physical und functional interfaces.

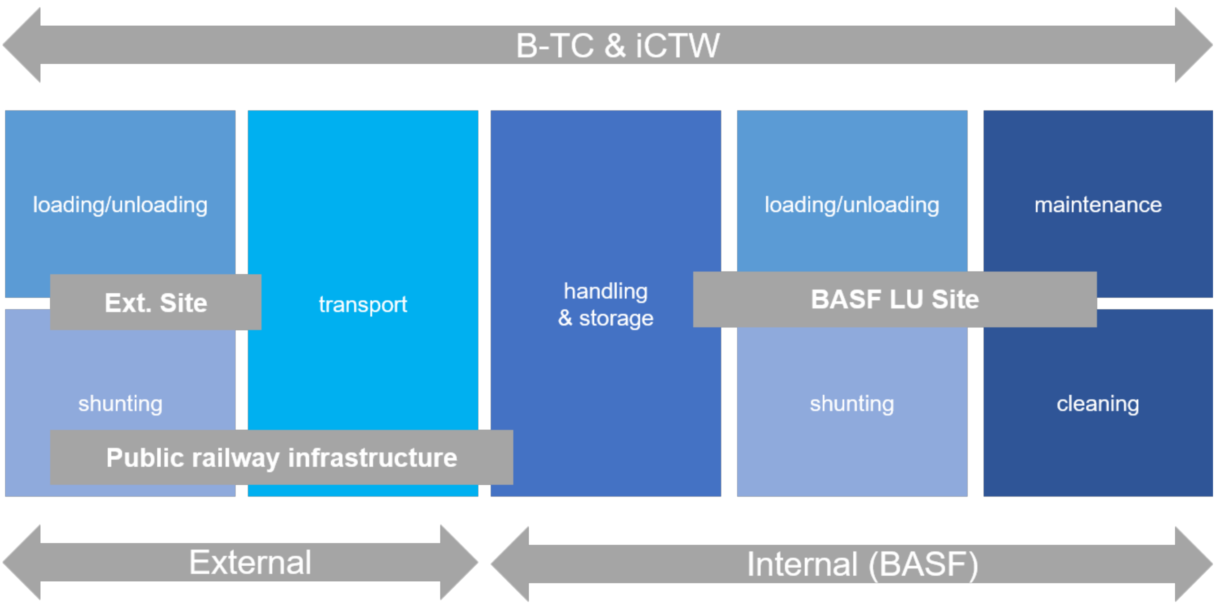


Figure 2: System Environment

4.4 Physical and functional interfaces

The systems utilization can be distinguished in various functions, as well as the interfaces in between. From an external perspective, the iCTW and B-TC need to be regarded as an inseparable unit. The new system is generally ranged in the railway transportation environment, where it meets all regulative requirements.

Transport & Shunting (Int. & Ext.) - The iCTW and B-TC unit is transported on the public railway infrastructure by external railway undertakings. Within the transport function, the new system is comparable to conventional intermodal or RTC transports. Respective units can either be transported in whole trains, convoys or as single cars. There are no further regulations to be considered. Like conventional transports of TC or RTC, the Railway Undertaking overtakes the transport unit at a specified place with a specified destination, ensuring the transport unit is transportable (i.e. tasks of wheeltapper). During the transport and shunting operations, no further regulations regarding the new system need to be considered except for the given technical constraints, as both sub-systems are generally approved. The following hazard identification and evaluation is circumscribed to these functions.

Internal and external loading and unloading operations - For loading and unloading operations, regulations as the RID are applicable which need to be considered externally and internally. Furthermore, internal or external site regulations can be applied additionally. Also, the loader is responsible to provide a transportable unit, considering the requirements of the transported products and the condition of the transport unit.

Internal handling - Internally, both sub-systems can be handled as unit or separately. The interface is the fully automated TCL in combination with the AGV, enabling a more flexible handling as already described.

Maintenance - According to their technical approval, the B-TC need to be revised every two and a half years following the RID regulations. Furthermore, the ITCO Acceptable Container Condition guidance is applied. The revision, as well as other repairs and maintenance activities or modifications of the B-TC are carried out in the BASF own, ECM certified wagon- and tank-workshop.

The iCTW are maintained and revisioned respectively, whereas applicable regulations are followed as with conventional rail tank cars or container wagons. Furthermore, additional guidance from the wagon owner, manufacturer, parts supplier and e.g. the VPI are deployed.

Cleaning - The B-TC are cleaned in a BASF owned cleaning facility with ten cleaning stations for rail tank wagons and tank containers. B-TC are cleaned in case of changes of the transported goods, by request from the production plants, before repair, maintenance and revision activities. After the cleaning process the B-TC are labeled with a cleaning certificate, which tracks the pre-product, cleaning procedure and date among other information.

4.5 System Environment

Within the railway environment, the same influences as for conventional TC and RTC can affect the safety level of the new system. These influencing factors can range from physical factors such as the weather and vibrations from the railway infrastructure, to operational ones as rules and procedures, staff competence and vandalism. However, acting within the same environment, there are no additional factors within the use of the new system.

4.6 Existing safety measures

The railway system is a highly regulated environment. Various regulation from several instances need to be followed and applied in the development, production and operation life phases of a system interacting within this system. Being approved for this environment, the system follows all applicable regulations. However, distinct features and safety aspects of the new system are further elaborated in this RA, leading to further safety measurements or suggestions to improve various regulations.

5. Hazard Identification and evaluation

The following chapter includes all identified and associated hazards with the new system. For each identified hazard at least one ‘risk acceptance principle’ (RAP) is applied in accordance with the CSM Directive. The RAP is chosen based on the most pragmatic and efficient approach to determine the acceptance level.

The hazards are identified in collaboration between railway experts of BASF and the TU Berlin, whereas BASF is supported in the assessment by TU Berlin as well. To assess the hazards, TU Berlin conducts several tasks to determine the safety level of the new system.

For each identified hazard, the associated risk is described in detail, including its potential cause. After classifying the hazard, a RAP is chosen to evaluate the risk. The evaluation procedure is explained in detail and the results of the assessment are presented. Based on which the safety level of the system is evaluated, and the risk acceptance is classified.

As in this RA a system is investigated which is already in use, it is relinquished to constantly update the system definition. However, to improve the overall safety level of the system, possible safety measures are introduced if considered as necessary.

However, it needs to be remarked that as the system is already approved and in use, no further safety measurements will be necessarily introduced, if an equivalent safety level and broadly acceptable risk acceptance is reached. Nevertheless, to further improve the safety level of the new system and of the railway system, further possible safety measurements are introduced.

The identified hazards are grouped, regarding the consequences for the sub-systems. Therefore, Group 1 engages hazards which are related to B-TC only, whereas Group 2 considers hazards for iCTW only. Group 3 engages hazards with consequences for both sub-systems and Group 4 consists of general hazards. However, different hazards within a group can also have effects on other hazards, can be directly related or can be the initiator for following hazards.

5.1 Hazard Group 1 – Mechanical Failure of the B-TC

Within this group, hazards are identified which have a direct impact on the safety level of the B-TC, having possible effects on the whole system environment.

5.1.1 Non-Conformance with Design Code

The design and production require the application of a variety of regulation and norms. The manufacturer of the B-TC is responsible to satisfy these requirements during the design and production, whereas especially the owner or user of the B-TC is responsible to maintain the condition of the B-TC during its utilization.

The design of the B-TC is based on the requirements given in RID Chapter 6.8, which clearly and extensively states the "requirements for the construction, equipment, type approval, inspection and tests, and marking of […] tank-containers […], with shells made of metallic material […]". (RID, 2019) Especially the following aspects need to be fulfilled to avoid possible hazards arising from non-conformity; minimum shell-thickness and material properties, welds and their inspections, requirements for construction, equipment, tests and marking, fastenings under maximum permissible load to absorb forces. Furthermore, structural safety requirements and tests of the International Convention of Safe Containers (CSC) are taken into consideration, as stackability, strength tests, lift tests and pressure tests.

Although a B-TC would not have been approved in case any non-conformity, a variety of hazards can be identified, which arise from a loss of the structural integrity. An exemplary hazard would be factures and fissures in the frame or vessel, caused by vibrations or forces during the usage of the B-TC. Such hazards can be affiliated to systematic failures as flawed calculations, wrong material choice, production faults, or a misaligned development in general. Eventually, such hazards can lead to severe effects on the health of people and the environment. Extraordinary hazards in terms of accidents are further investigated in another sub-chapter, as well as the overall driving behavior of the new system as a unit.

By applying the RAP 'Application of code of practice', it can be stated that the applied regulations, namely RID and CSC are widely recognized in the railway and TC domain. The B-TC of both manufacturers have been designed and build in accordance with these codes of practice, which is confirmed in the respective approvals. This includes the required requisite evidence maintained by simulations and tests. Bearing in mind that such regulations are under constant revision, verification and improvement, they represent the state of the art. TC in accordance with these regulations are capable to withstand all regularly occurring stresses and strains. Extraordinary hazards in terms of accidents are further investigated in another sub-chapter, as well as the overall driving behavior of the new system as a unit.

To ensure that each B-TC fulfills the requirements, each series is approved by an official assessment body. Additionally, each TC is controlled by an independent third-party service provider with a high expertise in the TC domain. Furthermore, each B-TC is checked by BASF employees before usage, ensuring a safe utilization.

To maintain the conformity during the life-cycle of the B-TC, already existing safety measures are applied by BASF. As for example, the given RID regulations for revisions of TC state a 30-month period of revisions. Furthermore, the ITCO ACC is applied to ensure an acceptable condition of the B-TC. Besides that, B-TC are constantly checked during unloading and loading processes, as well as by wheeltappers before and after transportation. During storage in the fully automated BASF depot, a leakage system is constantly monitoring the tightness of the vessels and fittings.

Being approved and under constant monitoring, the associated hazard can be categorized as broadly acceptable. Such general hazards are equivalent existing for TC as well. During development and production all relevant regulations have been applied, whereas during the life-cycle the B-TC are constantly monitored and maintained to ensure their conformity.

However, as the B-TC is a newly developed sub-system, which exceeds the size and capacity of conventional TC, additional safety measures and requirements can be introduced to improve the already high safety level. In regard of the discussed hazard, this could be namely an even more consistent monitoring of the B-TC. For instance, a B-TC could be checked within a ten-month interval, where the B-TC is examined by the BASF workshop or third-party service provider until the first full 5-year service interval is completed. A further possibility are automated checks where each time the B-TC passes a specific checkpoint, the B-TCs conditions is assessed by a variety of sensors and deviations automatically lead to a maintenance activity.

5.1.2 Impermissible loads

The B-TC are utilized for the transport and storage of liquid chemical goods, whereas each good requires a specific tank-code according to RID Chapter 3.2. (RID, 2019) The transport of dangerous goods inherits with a variety of hazards, as in accidents products could leak from the vessel which can lead to severe consequences for people and the environment. However, chemical products can be the cause for the hazard itself, leading to a loss of the structural integrity of the vessel. Especially acidic chemicals can lead to corrosion, which is a direct trigger for fractures and fissures in the frame and vessel.

To ensure that only suitable products are transported and stored within the B-TC of a specific tank type, it is necessary to apply regulations such as Chapter 3.2 of the RID. But furthermore, it is also necessary to control the suitability between the vessels' material and the product. Therefore, for each usage of the B-TC for a specific product it is verified, if the B-TC is suitable for the respective product. This verification is conducted between the user of the B-TC (i.e. loading or unloading business unit), material control experts and the so called 'Wagenmanagement', which oversees the allocation of B-TCs based on material compatibility.

Besides that, also during loading and unloading operations hazards can be identified as e.g. under- or overpressure, as the B-TC might not be properly vented or too much pressure is added. However, such hazards are also existing for conventional RTC and TC. Therefore, the operating employees are well trained and educated.

Applying the RAP 'Code of practice', it can be stated that the associated hazards are broadly acceptable. Applicable common regulations, as well as internal operating instructions determine the necessary safety requirements. Regarding the novelty of the B-TC, BASF employees are respectively trained, and external companies are provided with extensive instructions. It can also be registered that similar hazards are existent for conventional RTC and TC as well.

5.2 Hazard Group 2 – Mechanical Failure of the iCTW

Hazard Group 2 identifies hazards related to mechanical failures regarding the new system as a transportation unit. Accordingly, the B-TC and iCTW form the new system.

5.2.1 Non-Conformance with Design Code

The design and production require the application of a variety of regulation and norms. The manufacturer of the iCTW is responsible to satisfy these requirements during the design and production, whereas especially the owner or user of the iCTW is responsible to maintain the condition of the sub-system during its utilization.

Both iCTW versions under investigation have been designed and produced in accordance with European regulations, such as respective TSI- and AVV-provisions, UIC-leaflets and incorporating ISO, EN and DIN norms. This ensures the accordance with safe manipulation, physical configuration, compulsory measurements, functionality and strength properties, as well the necessary evidence in terms of documentation, tests and acceptance activities.

Although an iCTW would not have been approved in case any non-conformity, a variety of hazards can be identified, which arise from a loss of the structural integrity. An exemplary hazard would be factures and fissures in the wagon frame, boogies or superstructures, caused by vibrations or forces during the usage of the iCTW. Such hazards can be affiliated to systematic failures as flawed calculations, wrong material choice, production faults, or a misaligned development in general. Eventually, such hazards can lead to severe effects on the health of people and the environment.

Extraordinary hazards in terms of accidents are further investigated in another sub-chapter, as well as the overall driving behavior of the new system as a unit.

By applying the RAP ‘Application of code of practice’, it can be stated that the applied regulations, namely TSI, AVV and more as described in the system definition are widely recognized in the railway domain. The iCTW versions have been designed and build in accordance with these codes of practice, which is confirmed in the respective approvals. This includes the required requisite evidence maintained by simulations and tests. Bearing in mind that such regulations are under constant revision, verification and improvement, they represent the state of the art. Container carrying wagons in accordance with these regulations are capable to withstand all regularly occurring stresses and strains.

To maintain the conformity during the life-cycle of the iCTW, already existing safety measures are applied by BASF. As for example, the given regulations for revisions of wagons. Furthermore, the VPI European Maintenance Guide is applied to ensure an acceptable condition of the iCTW. Being a certified ECM and VPI workshop, the maintenance quality is ensured. Besides that, the iCTW are constantly checked by wheeltappers before and after transportation. An additional safety measure is an automated wheel flat detection system at the site entrance of BASF Ludwigshafen, where each entering and departing train is checked. In case of a detected wheel flat, the wagon is routed to the workshop.

Being approved and under constant monitoring, the associated hazard can be categorized as broadly acceptable. Such general hazards are equivalent existing for conventional carrying wagons as well. During development and production all relevant regulations have been applied, whereas during the life-cycle the B-TC are constantly monitored and maintained to ensure their conformity and safety level.

Possible further safety measures can be introduced to secure an even more constant monitoring. Currently, BASF plans to enhance the wheel flat detection by further sensors. This so called ‘Wayside Monitoring System’ aims to detect any defects and relevant parameters of a wagon to gain more insight in the life-cycle, as well as to initiate maintenance activities, ultimately leading to a more constant monitoring.

5.2.2 Impermissible loads / overloading / exceeding wheelset and meter load

Overloading a rail wagon is a common hazard in the railway domain. Depending on the transgression of the load limit, any wagons, boogies or wheelsets structural integrity can be affected negatively. Container carrying wagons in general are overloaded if the payload, the container weight plus product weight, exceeds the wagon specific load limit, which is dependent on the tare weight of the wagon itself and the maximum axle load, but limited to 90 tons in total.

The consequences of overloads can be fractures and fissures in the wagon frame, bogie or wheelset, whereas predominantly, the axle bearings are affected. Respective damages can have severe influences on the safety and the environment, as possible ramifications are derailments.

To ensure that wagons are not overloaded, various safety measures are existing. As responsible actor in this case, the loading entity is responsible to abide by the given load limits and to respectively fill the tank. Depending on the products density and the given minimum filling degree of 80 %, a suitable tank (i.e. volume) needs to be chosen to avoid overloading.

Considering BASF as loading entity, there are general safety measures to avoid an overloading as well as to detect an overloaded tank, irrespective if it is a conventional RTC, TC or B-TC. Loading stations are generally equipped with volumetric flow meters to monitor the loaded volume, based the calculated product weight and filling degree. Afterwards, during train formation each wagon passes an automated scale, which is generating a respective error message.

In case of the new system, iCTW are predominantly loaded with B-TC in the automated TCL. The TCL has an integrated scale in the crane, where deviations of the total permissible gross weight of 73,5 tons are automatically detected. Therefore, it is avoided that iCTW are overloaded before leaving the BASF site. Considering BASF as receiving or unloading entity, the total weight is either generally determined during shunting operations via the automated scale, or for the new system by unloading a B-TC in the TCL, although the responsibility lies with the delivering entity.

However, in case an overloaded wagon is detected, it is immediately sent to the workshop, where maintenance measurements are initiated in accordance with the VPI guidance.

Applying the 'Code of practice', it can be stated that the associated hazards are broadly acceptable. Overloads are a common hazard, for which applicable guidelines as well as safety measurements are well-established in the railway domain.

5.3 Hazard Group 3 – Mechanical Failure of the System

Hazard Group 3 identifies hazards which can arise during the transport and shunting of the B-TC and iCTW seen as a unit. Whereas in Group 1 and 2, more general hazards are identified and elaborated, Group 3 identifies hazards one a more refined and case-oriented level. For the identified hazards the RA is supported by the TUB, which conducted several scientific investigations to assess the associated risk. The scientific approaches are described in Chapter 5.2.1. Table 7 provides an overview over the scientific approaches (i.e. work packages) and allocates the assessable hazards.

To assess the hazards of Group 3, the risk acceptance principle of 'comparison with similar reference system' is applied, where the new system is compared against the conventional TC and

RTC systems, which are described in Chapter 5.2.1. Both conventional systems are demonstrated to have a level of risk which is considered acceptable and still qualify for approval. The comparison of reference systems enables the assessment of identified risks, investigating if an evaluated risk is less critical for a new system under investigation, or for the reference system of choice.

Hazard		WP 2	WP 3	WP 4	WP 5	WP 6
3.1	Mechanical Failure	(✓)				✓
3.2	B-TC lifting		✓	(✓)	(✓)	✓
3.3	Derailment	✓	✓			✓
3.4	Train separation	✓	✓			✓
3.5	Collisions			✓	✓	

Table 4: Hazard and TUB work packages

5.3.1 Reference Systems

Conventionally, liquid bulk chemicals including hazardous goods are transported via RTC or TC on the railway system. Being a TC in accordance with the applicable regulations, the B-TC on iCTW combines characteristics of both conventional systems. Therefore, these two conventional systems are considered as reference system in accordance with the corresponding risk acceptance principle. In this sub-chapter the reference systems are described, as well as a basic comparison to the system under investigation is presented. Figure 3 illustrates the reference systems of this RA, a conventional RTC and two ISO-TC on the 52' iCTW as used in the impact tests, as well as for the simulations.

Figure 3: RTC and ISO-TC

Conventional RTC are in use for the transport of chemical goods for decades and are available in highly diverse designs. Regarding the product and transportation requirements, BASF utilizes a variety of rail tank cars, differing in the tank-code, size and capacity, axle quantity and additional equipment. For reference, an RTC is chosen which can be compared to the B-TC in terms of the tank-code, capacity and payload, and total length (i.e. B-TC & iCTW).

Alternatively, chemical bulk goods can be transported via classical TC which range between 20' to 26', with a max. gross weight of up to 36 tons. Such TC can be transported via rail as on roads as well, representing a flexible and versatile transportation mode.

Table 8 summarizes the determining technical specifications of the chosen reference systems vessels, table 9 summarizes the technical specifications of the reference system wagons, respectively the frame and boogies of the RTC and table 10 (U.Deghela & M.Hecht, 2019) compares the general systems from a construction perspective based on the RID regulations.

Depending on the identified hazard and the scientific approach for assessment, different sets of the presented systems are utilized either as physical objects for applied tests, or as digital twins for simulations, which is further described in the following chapters.

Specification	***B-TC 45' (Van Hool)***	***B-TC 45' (Magyar)***	***RTC***	***TC 26'***	***TC 20'***
Tank-Code	L4BH	L4BH	L4BH	L4BH	L4BH
Vessel Length [m]	13.72	13.72	12.92	7.93	6.10
Capacity [m³]	63	63	66	35	26
Tare Weight [t]	7.70	7.95	25.16	4.28	3.86
Max. Payload [t]	67.30	67.05	64.80	31.72	32.14
Vessel material	1.4402	1.4402	1.4571	1.4404	N/A
Wall thickness [mm]	3.40	4.50	6.30	4.20	N/A
Eqv. wall thickness [mm]	7.07	9.01	9.15	7.46	N/A
Head wall thickness [mm]	7.90*	5.65	8.00*	5.20	N/A
Eqv. head wall thick. [mm]	15.82	11.31	11.62	9.23	N/A

*Table 5: Reference Systems Vessel Specifications // *before Forming*

Specification	*iCTW 45'*	*iCTW 52'*	*RTC*	*CCW 60'*	*CCW 40'*
Design Type	Sgmmnss	Sgmmns	Zacens	Sgnss	Sgmmns
Length over buffer [m]	15.15	17.35	14.90	19.64	13.61
Tare Weight [t]	16.50	16.50	25.16	20.00	17.50
Max. Payload [t]	73.50	73.50	64.80	70.00	72.50
Max. Axle Load [t]	22.50	22.50	22.50	22.50	22.50
Max. Velocity [km/h]	100	100	100	100	100
Boogie	TVP Ng-DBS	Y25Lsi(f)-C-K	Ba 642	Y25 Lss	Y25 Lssd
Brake-Type	Disc	CFCB	KE-GP	KE-GP-A	KE-GP-A
Buffer (Category)	L	L	A	A	A

Table 6: Reference Systems Wagon specifications

Difference	*RTC*	*TC & CCW*	*B-TC & iCTW*
Underframe Connection of the tank body	Fixed connection by means of a pad ensuring better distribution of dynamic loads (Source RID)	Secured by the separable connection of standard spigots and standard corner castings	secured by the separable connection of reinforced spigots and reinforced container corner castings
		It cannot be ensured that the dynamic and static loads are transmitted at the same time across the four connection points	
Presence of an upper gangway and spindle brake	Available: Thus, the speed can be controlled while running and thus protect the tank at train formation	Not available	
Buffer	Class A, B, C or L buffer	Class A, B, C or L buffer	Class L buffer with 150 mm buffer path
Total mass of the tank	up to about 80,000 kg	up to 36,000 kg	up to 73,500 kg
Minimum shell thickness of the tank body	Shells shall be not less than 6 mm thick if of mild steel or of equivalent thickness if of another metal (RID)	Shells shall be not less than 5 mm thick if of mild steel or of equivalent thickness if of another metal (RID)	
Capability of absorbing energy at each end of the wagon (without energy of buffer)	Optional Application of crashworthy buffers for tank wagons If RID regulation TE 22 applies	Not mandatory and applicable	
protection against the overriding of buffers	Optional presence of Device to protect against the overriding of buffers If RID TE 25 applies	Not mandatory and applicable	

Table 7: Reference System Comparison

5.3.2 TU Berlin Work Packages

The conduction of the RA is supported by the Technical University of Berlin, Mechanical Engineering and Transport Systems, Institute of Land and Sea Transportation, Chair of Rail Vehicles, which is represented by Prof. Dr. Ing. Markus Hecht and his research assistants. The following chapter broadly describes the scientific approaches by the TU Berlin. Gained insights and the respective assessment of the associated hazards, are elaborated in the respective hazard chapters.

WP 1 – U. Deghela & M. Hecht, 2019 – CSM Methodology

Work package 1 consist of support for the CSM methodology, where the TUB provides a paper-based comparison between the reference systems, identifies related hazards to the new system including a classification and risk analysis, determines respective risk acceptance principles and evaluates the identified hazards based on the findings of the other work packages. Furthermore, additional safety requirements and measurements are proposed. Work package 1 identifies eighteen hazards, which are elaborated

The findings of WP1 are incorporated in this RA report.

WP 2 – G. Katmer & M. Hecht, 2019 – "Investigation for sloshing movements"

Work package 2 investigates the running behavior and safety against derailment of the reference systems under representative operation and infrastructure conditions, taking effects from sloshing movements into account. To determine the safety level of the new system, experimental investigations are carried out with different tank loading levels as full, partial or empty. A train formation, consisting of the different reference systems as well as single wagons of the systems, are pushed and pulled through a double S-Curve with different velocities. The assessment is based on the analyzation of gathered data, which is collected by various sensors measuring displacements, velocities and accelerations at the wagons. Displacement sensors measure the vertical and lateral movement of the primary springs in different loading states, which is used to calculate the lateral force on the axle box. By comparing the gained parameters with their limit values in accordance with EN 14363, the running safety and safety against derailment under affects from sloshing movements are assessed. To further assess the effects from sloshing movements as lifting B-TCs, the systems under investigation are filled by 50% and emergency brakes are conducted with a velocity of 40 km/h. Furthermore, the collected data is used as input and validation measures for the simulations of WP3.

WP 3 – M. Gülker & M. Hecht – "Multi-body simulation for the investigation of sloshing movements and buffing"

Work package 3 assesses the running safety of the new system in comparison to the reference systems by multi-body simulations in different critical operational scenarios. Furthermore, derailment safety and B-TC lifting safety are examined, where effects from sloshing movements are considered. The scenarios of interest are critical situations in daily operations as; high velocities in canted curves, s-curves in shunting operations, and buffing impacts. Furthermore, the driving tests of WP 2 are simulated to validate the simulation models.

To assess the safety level of the reference systems, four sets (45' B-TC & 45' iCTW, 45' B-TC & 52' iCTW, 3 x 20' TC & 60' CCW, RTC) are modelled based on CAD-Models and parameter lists, focusing on precise representation of the running dynamics of the wagon, which are further influenced by forces initiated by the container and different load states (i.e. sloshing movements). The critical scenarios are simulated on modelled track layouts in accordance to EN 15839 (i.e. S-Curve) and EN 14363 (i.e. Canted Curve), whereas the effects during buffing are simulated one a straight track.

The assessment is based on the quotient of the lateral and vertical wheel contact force and given limits in EN 14363, as well as the wheel lift in accordance with EN 15839. For each system, velocity and scenario, the respective parameters are reviewed for each wheel of each wagon to determine the safety levels. Additionally, the possible lift of the B-TC is reviewed for each scenario.

WP 4 – T. Qiuyong & M. Hecht – "FEM Simulation"

Work package 4 assesses the crashworthiness of the new system in comparison with its reference system in collision scenarios. Therefore, the Finite-Element-Methodology (FEM) is applied to simulate frequently occurring accidents within the railway system. The FEM allows for a comprehensive and virtual modelling of complex structures to determine critical repercussions on the structures under investigation. Therefore, the system under investigation as well as the reference system are modelled as finite element models, as well as a dummy wagon, based on their material properties. Critical areas of the models, as the impact area, corner castings, spigots, buffers consist of finer meshes and more elements, as compared to non-critical areas, to gain more detailed results. To assess the safety level of the systems under investigation, with special interest to the varying wall-thickness between the systems, two scenarios are simulated; frontal impact and side-on impact, which are implemented in a FEM simulation software.

The frontal impact simulates the common accident, where a wagon of higher speed crashes into a stationary wagon. Therefore, a dummy model is designed, which directly hits the vessel head of the systems and corresponds to the impacting car of WP 5. Simulated with speeds of 15 km/h and 19 km/h, the simulations represent realistic impact velocities of 25 km/h and 27 km/h, where the buffers of the impacting cars would hit against each other first, before an overriding could occur. To assess the safety levels of all systems under investigation, namely both B-TC versions on both iCTW versions, 26’ TC on the iCTW and RTC are hit by the dummy and occurring the stress and plastic elongation values are compared to their respective failure limits.

Besides the common accident of overriding, side-impacts are simulated as well with a velocity of 25 km/h (i.e. shunting velocity). Therefore, both B-TC, a RTC and a 26’ TC are hit from a side, based on the geometry of a common turnover. Like the frontal impacts, the respective maximum values of stress and plastic elongation are compared to the occurring values.

WP 5 – G. Katmer & M. Hecht, 2019 – “Impact-tests”)

To further investigate the consequences of impacts under known and representative operations, work package 5 conducts impact-tests for frontal impacts (i.e. overriding). To assess the safety level of the system under investigation in comparison with its reference systems, a flatcar with a weight of 80 tons and raised buffers, is directly crashing into the fully braked tank heads of the systems with different velocities. Besides the comparison of the different systems, the different wall-thickness’ between systems, influences from different impact velocities and the distance between tank-head and buffer, are investigated. Therefore, the investigated systems are equipped with accelerometers and displacement sensors, which provide information regarding occurring forces. Each system is non-destructively tested before the impact to determine the initial condition of the tank-heads inside and outside, and of the spigots. Respectively, these areas are tested afterwards, too, to detect fractures and fissures. Furthermore, 3D-Scans are produced before and afterwards, to determine the volume change caused by the impact.

WP 6 – M. Gülker & M. Hecht, 2019 – “Impact-tests”

Work package 6 investigates the dynamic behavior of the new system during long-haul transportation, as well as in hump yard operations in comparison with the reference systems. To assess the safety level the systems under investigation are equipped with acceleration sensors, measuring accelerations on different positions and in different directions. The recorded accelerations are compared to the limit values set by guidelines and international regulations. Especially the area of the spigots and corner castings is examined regarding maximum longitudinal and lateral forces, whereas effects from sloshing movements are considered as well.

Therefore, a fully loaded B-TC, half loaded B-TC, fully loaded RTC and two fully loaded 26’TC on a CCW are repeatedly pushed of the hump yard over a time span of 4 months. Additionally, the buffing impact is simulated with different velocities in accordance with the MBS-Simulations (M. Gülker & M. Hecht, 2019a) and EN 12636, to assess the occurring impact forces.

Furthermore, the accelerations of a fully loaded and sensor equipped B-TC are recorded on several long-hauls between different BASF sites. The recorded accelerations are evaluated respectively.

5.3.3 Mechanical Failure of system and its components caused by accelerations and sloshing movements during shunting and transportation

During operations of railway systems, such as the new system under investigation and the reference systems, it is possible that accelerations exceed common values. Common values refer to accelerations which are consulted for development and construction, and which are defined in various applicable regulations and norms. Such transgressions can occur from excessive velocities or forces during transportation and shunting. Critical situations where high accelerations occur are e.g. high velocities in canted curves, or s-curves and buffing impacts in shunting and humping operations. The associated hazard in general can results in mechanical failures of the system. Regarding the new system, exceeding accelerations can lead to fractures and fissures in the iCTWs frame, boogies and axles, or superstructures as the reinforced spigots. Respectively, the B-TCs frame, vessel or superstructure can be damaged. Exceeded accelerations can furthermore to derailments of railway systems, this aspect is further investigated in Chapter 5.3.5. Ultimately, mechanical failures can lead to severe repercussions on humans and the environment directly (e.g. vessel fracture), or indirectly (e.g. broken spigots lead to loss of cargo). However, such consequences are equivalently existing for the reference systems. Furthermore, sloshing movements from the loaded liquid product can have effects of the structural integrity as well, as the moving mass can amplify accelerations and forces.

To elaborate the identified hazard and associated risks, the RAP ‘comparison with a similar system’, as well as ‘application of code of practice is’ applied.

Occurring accelerations during different scenarios are investigated in work package 6, where the reference systems and system under investigations safety level in terms of mechanical failures is elaborated. Of special interest in these investigations is the connection (i.e. the spigots) between a B-TC or TC and the respective CCW, which is a crucial component regarding occurring forces and accelerations.

To assess the accelerations occurring during conventional transports on long-hauls, a fully loaded B-TC on iCTW is equipped with acceleration sensors in crucial positions as close to the spigots and corner castings. Applying the RAP ‘application of code of practice’, the measured acceleration values are compared to the maximum allowable forces defined in EN 12663-2. Data is recorded in a total of 17 runs between BASF Ludwigshafen and BASF Schwarzheide or Antwerp, resulting in total of around 15.000 km, where the system is transported on the railway system. Eventually, it can be stated that during the data gathering no critical states (i.e. accelerations above critical values of EN 12663-2) are detected. Upon visual inspection of the overall system and destructive free test of the spigots and corner castings, no mechanical failures of the system can be assessed.

During hump yard operations, severe shocks and accordingly accelerations can occur when a humped wagon impacts a standing wagon, which can ultimately lead to mechanical failures if limit values are exceeded. To assess the occurring accelerations for the systems under investigation, both named ‘risk acceptance principles’ are applied. In comparison to the given limit values of EN 12663-2, the occurring accelerations at the BASF own hump yard in Ludwigshafen, two new systems are equipped with accelerations sensors; two B-TC on iCTW, which are filled partially (i.e. 50 %) and fully. Respectively, additional effects from sloshing movements can be investigated. To account for the principle of comparison, a conventional CCW with two 26’ TC is equipped with accelerations sensors as well. Data is recorded over a time span of five months, where the systems under investigation are continuously pushed over the hump yard, running through rail brakes into the sorting tracks. For the B-TC/iCTW sets, two rail brake configurations where used, leading to different velocities at the impact (i.e. high & low), whereas low velocities refer to the conventionally used configuration.

Based on the determined limit values in accordance with EN 12663-2 it can be stated, that the respective limit values in regard of the wagon frame are exceed by the new system in a fully loaded state in less than 4 % of the recorded impacts for velocities higher 5 km/h. However, the acceleration limit refers to wagons of the category F-II. Since the wagon is tested by the manufacturer for the F-I category, and humping operations are approved, the respective calculated acceleration limit of 2,8 g is not exceeded by the new system in both loading states. The limit value for the spigots are not exceeded as well. For the partially loaded, as well as for the conventional system which was tested 23 times, neither the accelerations at the spigots nor at the wagon frame are exceeded. Neither destructive free tests at the spigots, as well as visual tests at the wagon frame of all systems under investigation indicate damages. This leads to the assumption of supported stiffness by the B-TC, which supports the force absorption.

Additionally, the hump operation is simulated using the methodology presented in work package 3, investigating occurring forces at the spigots during humping operations for the systems under investigation in different loading states. The simulation results indicate that the new system reaches limit values for forces at the spigots and wagon frame, marginally earlier than the conventional system. However, respective limit values are reached with significantly higher velocities as in real hump operations.

Conventional shunting operations and their critical situations are further evaluated based on the collected acceleration data during the long-haul and hump operations tests. In comparison to the limit values according to EN 12663 it can be stated that no exceeding values are detected for all systems under investigation. Furthermore, in comparison with the conventional system, similar accelerations are detected.

Summarizing the conducted investigations, there were no critical accelerations in comparison to the code of practice or to the compared reference system, as well as no deformations and damages on the system during the long-haul tests, as well as during the buffing tests. These results indicate a similar safety level as for the conventional system. Therefore, the associated risk can be classified as broadly acceptable.

However, it needs to be remarked that for the new system additional safety measures can further improve the safety level. Although critical accelerations regarding the F-I category are not detected, which the iCTW could be categorized as due to its reinforced spigots and the long-stroke buffers, critical values are reached regarding the F-II limit values. Therefore, the TUB suggests reducing the inspection intervals to assess the underframe structure of the wagon. However, due to the low velocities the occurrence of respective consequences is marginal. However, BASF intends to improve the inspections intervals in terms of the already presented wayside monitoring approach. Accordingly, BASF intends to reduce the maintenance intervals of iCTW, which pass the humpyard on a regular basis, down to 3 years.

5.3.4 Unintentional B-TC lifting during operation and accidents

Conventional TC and B-TC are connected to the CCW or iCTW only by four spigots. Such spigots keep the TC and B-TC horizontally in position. However, a vertical securement is given only by the mushroom-shaped tip of a spigot. Therefore, during operations within the railway system conventional TC and B-TC might be lifted due to accelerations, sloshing movements or a tilting of the system, ultimately leading to a loss of connection between wagon and TC. Eventually, a loss of connection between the sub-systems can lead to severe consequence for humans and the environment. However, a TC falling of a CCW is highly unlikely during conventional railway operations.

To investigate the possibility of a B-TC lifting, the RAP of 'comparison to similar system' is applied, following the methodology of work package 3. The simulations conducted in work package 6 investigate possible liftings in comparison to the conventional TC system. It can be stated that with increasing velocities, the conventional TC is much more likely to lift by buffing impacts due to its lighter gross weight. Whereas the conventional TC in an empty state at a velocity of 10 km/h lifts about 7mm, the B-TC do not lift at all. The results indicate a higher safety level for the B-TC.

Furthermore, the hazard is investigated in work package 3 where possible lifts are investigated for critical transportation scenarios as a s-curve and canted curve. For both scenarios and B-TC / iCTW combinations, the maximum lift is determined at 0.29 mm. Regarding the overall height of a spigot of approximately 100 mm a loss of the B-TC is nearly impossible. Due to the minimal lift result of the B-TC and no known incidents with conventional TC, it is relinquished to further investigate lifts of conventional TC.

Considering all conducted investigations including the long-term trails, sloshing investigations, impact-tests and simulations, for neither the new system nor the conventional TC system, critical lifts could be detected. Especially, the braking test in work package 2 did not show a container lift for a partially loaded B-TC. Therefore, the associated hazard is classified as broadly acceptable and no further safety measurements are required.

5.3.5 Derailment due to driving behavior and sloshing movements in vessel

The running behavior of a system within the railway system is a crucial factor for the safety level, whereas running behavior refers to the driving characteristics under known and representative operations und infrastructure conditions. Structural properties and the geometry of railway system can affect driving behavior negatively (e.g. high pivot point) or positively (low pivot point). Furthermore, the filling degree has influences on the driving behavior as well, as a moving mass can initiate further forces and accelerations. Ultimately, negative effects can lead to hazards as derailments, with possible severe consequences to humans and the environment.

The running behavior of the new system is investigated applying the RAP ‘comparison with similar system’. Accordingly, the driving characteristics of the new system are elaborated in comparison with their conventional counterparts. Therefore, driving tests and simulations are conducted by the TUB, as described in work package 2 and work package 3.

Conducting practical driving tests, work package 2 compares the driving behavior of the new system with the reference system TC by investigating the lateral forces on the axle boxes based on EN 14363. Therefore, the systems under investigation are equipped with sensors and the gathered data is compared accordingly. Under special consideration are effects from sloshing movements of partially loaded systems, regarding the loading restrictions for TC (RID 4.3.2.2.4). Critical values are determined based on the calculated lateral force on the axle box and the permissible maximal lateral force. By comparing the gathered parameters, it can be stated that for all systems under investigation critical values are not exceeded. For both systems and increasing velocities the extracted values are almost constant and the extracted values decrease with increasing load. Correspondingly, no critical sloshing movements are detected and have no impact on the driving behavior and safety against derailment.

Additionally, critical operation situations within the railway system are simulated for the systems under investigation, where the quotient between lateral and wheel contact force in accordance with EN 14363 and EN 15839 is evaluated. The elaborated parameter is determined for each wheel of each wagon over the total length of the different simulated tracks with different velocities. Furthermore, the wheel lift is determined for each scenario and wagon, where effects from sloshing movements are considered as well. By comparing the gathered parameters, it can be stated that for all systems under investigation no critical states are detected, neither for the critical s-curves nor canted curves. The probability of derailment for a B-TC transported on the 45’ iCTW is less than for the conventional systems due to its boogie type, whereas the 52’ iCTW reached an equivalent safety level. Furthermore, there are no negative impacts from sloshing movements for all investigated system.

Summarizing the conducted investigations, it can be stated the new system has an equivalent safety level as the reference systems, whereas the combination of 45’ B-TC and iCTW represents an improved safety level in the railway system in terms of driving behavior and safety against derailment. Accordingly, the associated hazards can be determined as broadly acceptable and no further safety requirements are needed.

5.3.6 Unwanted train separation due to sloshing movements

Whereas sloshing movements can have a negative impact on the driving behavior due to lateral movements of the liquid, lateral movements can have an impact on the couplings and can lead to unwanted train separations. Accordingly, excessive longitudinal tensile forces may break the couplings, when the sloshing in different vessels occurs phase-delayed. A broken coupling leads to the separation of a train and the remaining wagons (i.e. not connected to train) pose a hazard for following trains. Whereas lost wagons are detected on monitored rails by the respective safety measures, especially in un-monitored shunting areas (velocities < 25 km/h) this can lead to incidents with impacts on the safety of humans and the environment.

To investigate the longitudinal impacts of sloshing movements on the train connection, work package elaborates the hazard based on the RAP ‘comparison to similar system’. It can be stated, that longitudinal forces from sloshing movements have no evident effect on the contact forces between single wagons of all reference systems. Therefore, it can be concluded that the associated hazard is broadly acceptable and no further safety requirements need to be introduced. The new system reaches an equivalent safety level as the reference system.

5.3.7 Damages caused by collisions – overriding and side impact

The most critical hazards occurring in the railway system can be generally affiliated to accidents, where trains or single wagons collide with other railway participants. Collision can not only cause derailments with capsizing wagons or falling TC, already the impact of two systems can cause severe damages to the vessels or the systems structural integrity. Both cases can ultimately cause leaking of hazardous goods, which can have severe consequences for humans and the environment. Common accidents, especially during shunting operations, are overriding where a wagon climbs onto another wagon on a track, and side impacts at turnovers. Such consequences from the associated hazards are equivalently existing for the system under investigation, as for the reference system. However, due to the structural difference, as wall-thickness and the connection between vessel and wagon (i.e. fixed for RTC, loose for iCTW/CCW), similar impacts can have different repercussion regarding the safety level.

Therefore, work packages 4 and 5 investigate the safety levels of the new system under investigation in comparison to the reference systems for different impact scenarios, applying the RAP ‘comparison to similar system’. Accordingly, work package 4 simulates the accident scenarios of a side-impact, as well as reproduces the overriding impacts, which are conducted in work package 5. For each impact scenario, the wall-thickness and equivalent wall-thickness is under special consideration, to classify the respective damage patterns and dimensions. Based on the damage patterns, volume changes, and more parameters the safety level of the different systems can be determined.

To assess the safety level of the systems under investigation in work package 5 realistic overriding impact-tests are conducted as described in chapter 5.3.2. Accordingly, the crashworthiness under known, representative operation and infrastructure conditions of the systems is investigated. Therefore, five different systems with filling degrees of 95 % are impacted by a specialized wagon, which is pushed into a fully braked system. Equipped with accelerometers and displacement sensors, further insights can be gained.

Comparing the damages between the reference systems (45’ B-TC Van Hool / RTC /26’ TC) it can be stated, that the Van Hool B-TC is damaged the least. With a head wall-thickness of 7.9 mm and a non-existing safety distance between head and buffer, the B-TC was deformed by 90 l and without leakages. However, the RTC with a wall-thickness of 8,0 mm (before forming) and safety distance of 300 mm is deformed by 100 l without leakages. Comparing just these two reference systems, it can be concluded that the used stainless-steel of a certain wall-thickness at the head is more resistant against impacts and respectively, the additional safety distance of merely 300 mm has no positive impact on the safety level, as the vessel with less safety distance resources and a thinner head wall-thickness is deformed less. The conventional TC is deformed by 390 l without leakages. Having the lowest head wall-thickness of the reference systems of 5.2 mm but the same material as the B-TC, one can conclude that the B-TC heads can be even more stressed before fractures and fissures would occur. However, as the impact velocities represents realistic maximum shunting velocities, impacts with higher velocities are not expected during operations. Nevertheless, higher velocities are tested for the Van Hool B-TC as well, resulting in a deformation of 210 l, without leakage indicating an adequate strength for higher velocities as well and further resources till failure.

Accordingly, comparing both B-TC versions it can be stated that the Magyar B-TC with a head wall-thickness of 5.65 mm is significantly more deformed with 190 l, but without leakage. This supports the inferior material characteristics of the used material (i.e. 1.4402), as no critical states are reached even with more deformation at a smaller head wall-thickness. Regarding the distance between head and B-TC frame in comparison to the conventional TC it can also be stated, that the B-TC design is inferior accordingly. With half a foot less distance between frame and head, the deformation is more than a half less then at the conventional TC. Table x illustrates the results of the impact tests with a velocity of 15 km/h in comparison to the reference systems.

System	Van Hool	Magyar B-TC	RTC	TC
Impact				
Deformation	90 l	190 l	100 l	390 l
Leakage	No	No	No	No
Safety Reserve	38.5 %	46.7 %	5.7 %	53.5 %

Table 8: Impact-Tests Results (15 km/h) incl. simulated safety reserve result

Furthermore, the effects of different wagon lengths for B-TC are investigated. Whereas the B-TC on a 45' without any safety distance are deformed by 90 l and 190 l, a Van Hool B-TC is not deformed on a 52' iCTW. Due to a distance between head and buffer of 3.5 foot, the overriding wagon does not reach the vessel. It can be concluded that an improved safety level is only reached with a significant distance between buffer and tank-head, whereas the 300 mm for RTC do not have a sufficiently positive effect.

The conducted impact-tests indicate that the chosen head wall-thickness for the B-TC is sufficiently dimensioned to protect the vessel from fissures and fractures from overriding impacts and an improved safety level in comparison with the conventional systems is accomplished. Furthermore, it can be stated that with the impact-tests the frames of the B-TC and the conventional TC are not damaged. However, the connection between wagon frame and vessel of the RTC is damaged, as parts of a connection plate are fractured. Also, the tested iCTW are solely damaged at the buffer due to the high impact forces and some wheelsets are damaged in terms of flat-spots. During all impact-test, no derailments occurred.

Additionally, the conducted impact-tests are simulated to gain further insights regarding the material specifications in terms of yield strength and stresses, by determining safety reserves. Following the methodology of work package 5, the B-TC versions are compared to their conventional counterparts, with each other and in regard of different wagon lengths, whereas the respective strain distribution and plastic elongation is considered for the safety reserves. Figure 4 illustrates impact simulations in general.

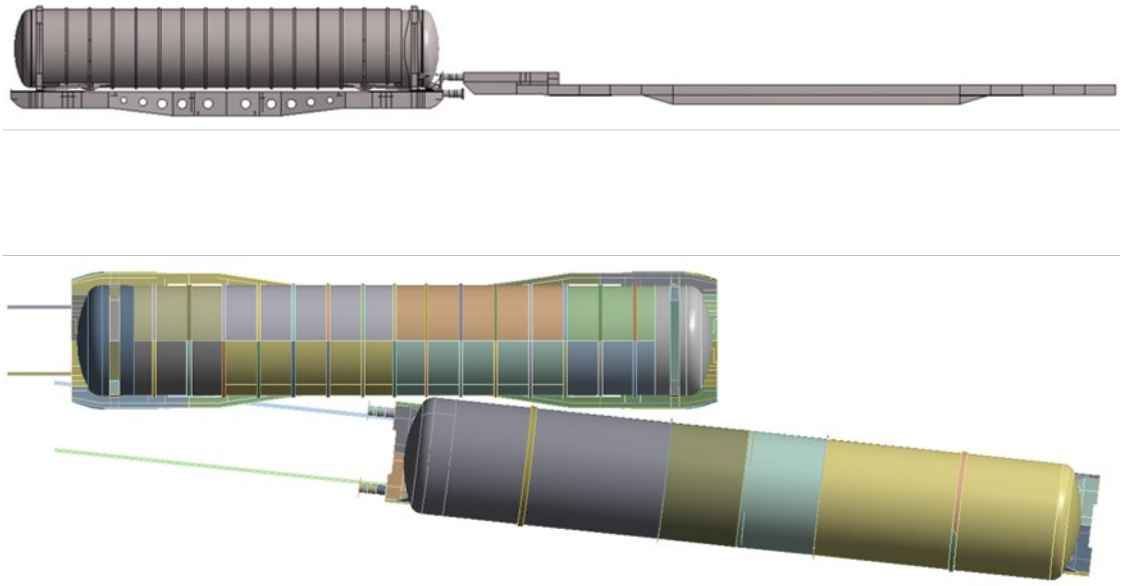


Figure 4: Impact Simulations (overriding - top, side impact - bottom)

Regarding the comparison of all systems under investigation for a simulated impact velocity of 15 km/h, all systems remain without leakage. However, based on the material properties varying safety reserves remain. Although the Magyar B-TC has a head-wall thickness of 5.65 mm only, the construction of the tank head enables a longer path for plastic deformation. Therefore, a safety reserve of 46,7 % remains, whereas 38.5 % remain for the Van Hool B-TC. For the conventional TC 53.5 % remain, as the head is shaped comparable to the the Magyar B-TC, with the highest equivalent head wall-thickness. Although the RTC has a safety distance of 300 mm and the highest wall-thickness, only 5.7 % remain. Accordingly, the same conclusions can be drawn as from the real impact-tests. Comparing the B-TC which each other, it can be stated that the geometry of the head has a positive impact on the safety reserve.

Comparing the safety reserves of the simulations with a higher velocity of 19 km/h, it can be stated that the B-TC gain advantage over the conventional system. Whereas the TC has a safety reserve of -23.3 % and the RTC of -42.9 %, which for both leads to material failures, the Magyar B-TC remains with 0% and the Van Hool B-TC remains with a safety reserve of -17.9 %. For the comparison between different iCTW lengths, it can be stated that the B-TC on top of a 52' iCTW is not impacted by the overriding wagon as in the impact-tests as well. The simulations results support the findings of the impact-tests, indicating that the B-TC improve the safety level in terms of the associated hazard of overriding. The results of the simulations are summarized in table 9.

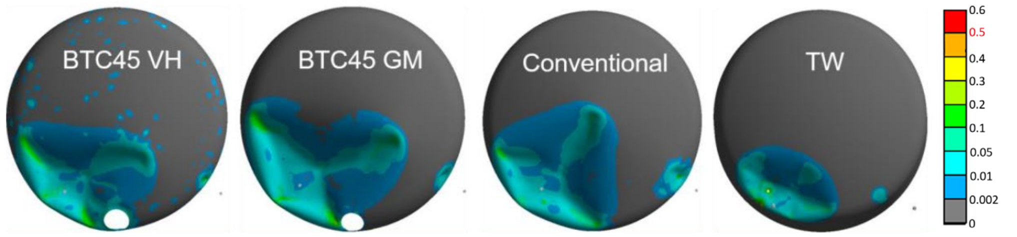
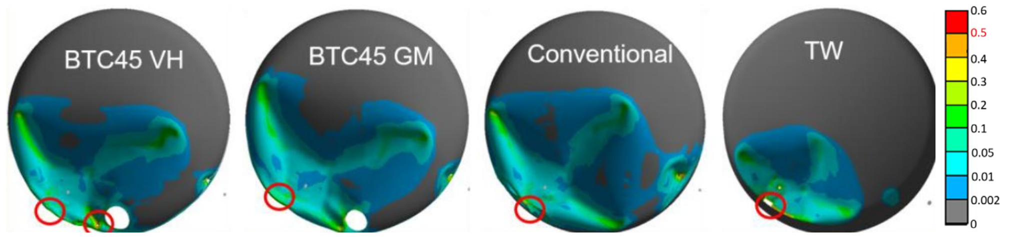
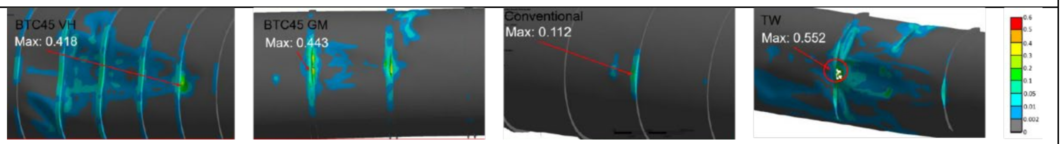
System	Van Hool B-TC	Magyar B-TC	TC	RTC
Overriding 15 km/h				
Impact / Plastic Satrain				
Safety Reserve	38.5 %	46.7 %	53.5 %	5.7 %
Overriding 19 km/h				
Impact / Plastic Strain (circle indicates max)				
Safety Reserve	-17.9 %	0 %	-23.3 %	-42.9%
Side Impact				
Impact / Plastic Strain				
Safety Reserve	16.4 %	7.7 %	71.6 %	-57.7 %

Table 9: Simulation results

Beside overriding, side-impacts are a relatively common accident in the railway system, whereas such accidents mainly happen during shunting operations. Accordingly, following the methodology of work package 4 and the simulated overriding impacts, side-impacts are simulated to determine the safety level of the system under investigation in comparison with its reference systems. The impacting car is a conventional RTC, which impacts both B-TC versions on a 45' iCTW, a similar RTC and a 26' TC on the 52' iCTW. As there is no CAD-Model of a conventional CCW available, the 52' iCTW is used as alternative. Comparing the system under investigation for simulated side-impacts with a velocity of 25 km/h (i.e. max shunting velocity), whereas the plastic deformation of the vessels in considered only, it can be stated that TC in general have a greater crashworthiness as the conventional RTC. Only for the RTCs vessel the maximum plastic elongation is exceeded, indicating a failure of the vessel as a safety reserve of -57,7 % is archived. Being equipped with a total of 15 reinforcement rings, the Van Hool B-TC with a wall-thickness of 3,4 mm remains with a safety reserve of 16,4 %, whereas the reinforcement rings account for a higher bending stiffness. Respectively, the Magyar B-TC with a wall-thickness of 4,5 mm and seven reinforcement rings remains with safety reserve of 7,7 %. Due to the lower number of reinforcement rings, the bending stiffness is less, and the occurring deformation is larger. However, it can be observed that for the Van Hool B-TC more deformation is located on the vessel itself, whereas for the Magyar B-TC more deformations are located at the reinforcement rings. This is reasoned as the radial stiffness of the Magyar B-TC is larger, due to the greater wall-thickness. For the conventional TC with a wall-thickness of 4,2 mm and four reinforcement rings, a safety reserve of 71,6 % is archived. However, as no CAD-Modell of a conventional CCW is available, the 26’ ISO-TC is simulated on a 52’ iCTW. Accordingly, due to the geometry of the iCTW itself and the position if the TC on the iCTW, it can be observed that most energy during the impact is absorbed by the iCTW. The system is hit further forwards then the remaining systems, where the iCTW is wider and therefore secures the TC. Respectively, an impact on a conventional CCW might lead to similar deformations with a lower remaining safety reserve. In general, the geometry of the iCTW with a wider body structure above the boogies benefits the crashworthiness of the new system in general as a major amount of the impacting forces are absorbed by the car body. Therefore, the RTC which does not have a comparable geometry and structure fails for the car body as well. Furthermore, it can be stated that the impacting RTC is more deformed for the impact with a RTC, as compared to the impacts with the TCs. Based on the obtained results, TC in general including B-TC have a higher safety level in case of side impacts than conventional RTC.

Regarding the results of both simulated impact scenarios, which both apply the RAP ‘comparison to similar system’, one can conclude that the new system under investigations improves the safety level of the railway systems in terms of the investigated accident scenarios. The B-TC clearly improves the safety level for overriding accidents in comparison to both conventional systems. For side-impacts the B-TC exceed the safety level of the conventional RTC, whereas for the conventional TC it needs to be regarded that it was simulated on a beneficial iCTW. Accordingly, the respective hazards associated with the accidents under investigation can be classified as broadly acceptable and no further safety measures need to be introduced.

5.4 Hazard Group 4 – General and Operational Hazards

5.4.1 Unidentified damages by wheeltapper or during maintenance

Due to the novelty of the new system and specific design features, such as the overlapping wagon frame, wheeltappers can have issues identifying damages on the system, especially on the system. Similar, defects might be not detected during maintenance activities such as revisions. Eventually, unidentified damages can lead to severe consequences for humans and the environment.

By applying the RAP ‘Application of code of practice’, it can be stated that applicable regulations are widely recognized in the railway and TC domain. Such regulations include national and international instructions and guidelines, regarding the tasks of wheeltappers (e.g. VDV 915). Furthermore, the employees are repeatedly trained and informed regarding critical aspects during their inspections.

In terms of maintenance activities, the same risk acceptance principle can be utilized. As elaborated before, the BASF workshop is certified in accordance to e.g. the Entity in Charge of Maintenance. This ensures the quality of maintenance activities and reduces the risk of undetected damages. Besides that, several guidelines from various instances such as the VPI, but also from wagon owners are incorporated in respective checklists.

Similar hazard exists for the conventional RTC and TC as well, as specific design features of different wagons and tanks can negatively influence the detection of damages by visual examination. However, for all systems under investigation, the same regulations are applicable. Therefore, the identified hazards can be classified as broadly acceptable.

5.4.2 Exposition to dangerous goods during maintenance

During maintenance activities employees can get in contact with hazardous goods, which can have severe consequences for the employee’s health. Although each tank is throughout cleaned before any activity, there can be residues in so called dead spots. Such spots can be existing in e.g. ball valves, between two valves, or regarding the new system B-TC in the so-called T-Pipe, where residues are not spilled out during the cleaning procedure.

Applying the RAP ‘comparison with similar reference system’, it can be stated the same procedures to ensure the employees safety are applied for all systems under investigation. Before any maintenance activities at the tank are started, the tank is cleaned in a specialized facility under consideration of the last contained product which determines the cleaning procedure in terms of temperature, pressure, additives and more. After cleaning, a certificate is issued, providing information about the last product. Based on the certificate, a permission to work on the tank is created. This permission states the necessary personal safety equipment, the respective employee must wear when the tank or any fitting is opened.

The hazard exists for very tank with maintenance activities and the same safety measures are implemented for the B-TC as well. Therefore, the risk can be classified as broadly acceptable.

6. Conclusion

The presented risk-assessment determined the safety level of the new system, B-TC and iCTW, in accordance with the CSM directive. By applying the risk acceptance principles of 'code of practice' and 'comparison to a similar system', the system under investigation was examined regarding applicable regulations and in comparison, to conventional RTC and TC.

The proposer BASF was supported by the Technical university of Berlin, which conducted several scientific approaches to determine the safety level of the systems for the respectively identified hazards. The results of the conducted RA can be summarized as for each identified hazard, the associated risks are broadly acceptable. It is show that a least an equivalent safety level is reached for the new system under investigation in comparison to its conventional counterparts. Furthermore, it is shown that for several hazards a higher safety level is reached. Table 11 summarizes the results of the identified hazards where the RAP 'comparison to similar system' is applied. Accordingly, a respective relative classification of the safety levels of each system is presented.

Hazard	**B-TC Van Hool**	**B-TC Magyar**	**Rail Tank Car**	**ISO-TC**
Derailment	++	++	+	+
Mech. Failure due to accelerations	+	+	+	+
Overriding Deformation (15 km/h)	++ (52' iCTW ++)	- (52' iCTW ++)	+ (plus 300 mm)	--
Overriding Safety Level (15 km/h)	- (52' iCTW ++)	+ (52' iCTW ++)	--	++
Overriding Safety Level (19 km/h)	++	++	--	-
Side-Impact	+	+	--	(++)
Overall	**++**	**++**	**-**	**+**

Table 10: Safety Levels of Systems Under Investigation (++ highest safety level / + high safety level / - low safety level / -- lowest safety level)

In accordance with the conducted RA, it can be stated that the new system fulfills all requirements, as e.g the required wall-thickness, regarding the applicable codes of practice, which is also the case for maintenance and operational guidelines. Furthermore, it can be stated that for derailments the new system exceeds the already high safety level of the systems in comparison. In terms of mechanical failures from accelerations during operations, the new system reaches an equivalent safety level. For the simulated and conducted overriding impact tests, it can be stated that the new system reaches an equivalent safety level, whereas for specific combinations especially in comparison to the conventional RTC a higher safety level is obtained. For the simulated side-impacts, an equivalent safety level is reached in comparison to the conventional TC, whereas a higher safety level is reached compared to the RTC. From an overall perspective, it can be summarized that the new system reaches a higher safety level as the conventional counterparts.

In accordance with the CSM directive, no further safety measures need to be introduced for the new system, as all risks are classified as broadly acceptable and a respective safety level is reached. However, based on the gained insights by the scientific investigations, several topics can be addressed to improve the overall safety level of the railway system.

Accordingly, the reinforced spigots of the new iCTW improve the safety level during transportation and especially, during shunting operations. Respectively it is advisable to introduce reinforced spigots for all F-I approved CCW, as the reinforced structure from a stronger material allows for higher possible accelerations without failures.

Based on the investigations regarding the sloshing movements of liquids inside the vessels, it should be discussed if the minimum and maximum filling level for TC transports on rail is necessary. The results clearly indicate that there is no expected risk from filling degrees between 20 % and 80 %. Therefore, the respective regulation could be neglected.

All conducted scientific approaches also lead to the assumption that a lifting of the new system is not expected during conventional utilization. Furthermore, the impact tests indicate no danger of rolling over or similar.

Whereas for RTC respective special regulations are applicable for specific products, namely RID TE 22 and TE 25, there are no comparable regulations for TC. The impact tests and simulations indicate, that TC in general have a higher crashworthiness in terms of overriding impacts. Accordingly, there is no need to adjust respective regulations for TC. However, as the tests indicate that an increased safety level is only reached by a significant enhancement of the safety distance between vessel head and buffer, it could be discussed if respective products should be transported on longer CCW. Nevertheless, is should be regarded that respective products are transported in vessels with an even higher head wall-thickness already (i.e. tank-code).

Being the most critical structural difference between TC and RTC, the general wall-thickness is of further interest. The conducted RA including the scientific investigations indicate that the combination of the used material and wall-thickness does not lead to a decreased safety level. Instead, the general construction of the B-TC improves the safety level in comparison to the widely used ISO-TC and RTC. Accordingly, it is rather advisable to reassess the given regulations for the conventional systems to maintain an appropriate safety level in the railway system. Therefore, it should be discussed if the respective regulations (TE 22 & TE 25) are still reasonable and the minimum wall-thickness for conventional systems should not be further reduced.

Based on the obtained on the results of the RA, there are no indications to implement specific regulations for B-TC, which are based on the respective volume. However, it should be discussed if recent developments in the RTC development as self-supporting vessels can maintain an appropriate safety level.

7. Declaration Article 16

Hereby, BASF (i.e. the proposer) declares, based on the results of this Risk-Assessment in accordance with the CSM directive, that all identified hazards and associated risks are controlled to an acceptable level.