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CARBODIN
CAR BODY SHELL,
DOORS AND INTERIORS

Deliverable D 12.5
Report on year 1 CARBODIN demonstrators

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1. Executive Summary

The present document has been prepared to provide a detailed overview of the work undertaken by CARBODIN during the first year of the project. D12.5 includes a collection of the publishable information from the WS deliverables related to the demonstrators.
This report will include the advancements in the three blocks forming the project, and as such it will be composed of three parts, which showcase the project advancements in the car body shells block (namely, WS1, WS2, WS3, and WS4), in the doors block (WS5, WS6, and WS7) and in the interiors block (WS8, WS9, WS10, and WS11).

Due to the delays the project has been subject to, this report includes 6 deliverables: D2.1, D5.1, D6.1, D8.2, D10.1, D11.1. The remaining deliverables will be included in the second version of this report, D12.6 “Report on year 2 CARBODIN demonstrators”.

2. Abbreviations and acronyms

Abbreviation / Acronym	Description
AE	Acoustic Emission
ASL	Average Signal Level (a measure of the continuously varying and “averaged” amplitude of the AE signal)
CMP	Compression Moulding Process
HMI	Human-Machine Interface
LCC	Life Cycle Cost
MEMS	Micro-Electro-Mechanical-Systems
NRC	Non-Recurring-Costs
PoC	Proof of Concept
RMS	Root Mean Square (a measure of the continuously varying AE signal “voltage” into the AE system)
SHM	Structural Health Monitoring
TD	Technical Demonstrator
VIP	Vacuum Infusion Process
WS	Work Stream

3. Background

The present document constitutes the Deliverable D12.5 “Report on year 1 CARBODIN demonstrators” in the framework of the CARBODIN project (topic S2R-OC-IP1-01-2019, GA ID: 881814), which contributes to the ongoing PIVOT2 project (topic S2R-CFM-IP1-01-2019, GA ID: 881807), and this deliverable is related to TD 1.3 “Car body Shell Demonstrator” Tasks 1.3.4 and 1.3.5 , TD 1.6 “Doors and Access Systems Demonstrator” Task 1.6.4, and TD 1.7 “Train Modularity in Use (TMIU)” Task 1.7.3 and 1.7.4, of IP1 “Cost efficient and reliable trains, including high capacity trains and high speed trains” (according to the MAAP TD Gantt-chart in document Ref. Ares(2019)7676192 - 13/12/2019 whose date printed in the document is 14th of November 2019, Brussels).

4. Objective/Aim

This document has been prepared to provide a collection of the publishable information from the WS deliverables related to demonstrators. This report includes the advancements in the three blocks forming the project, and as such it will be composed of three parts.
The first section will showcase the project advancements in the carbody shells block. This first section focuses on the work done in the field of on-board data processing in the first year.
The second section will include the advancements in the door block and covers the work undertaken in the fields of modular tooling and thermal and acoustic isolation.
Lastly, the report will consist of the progress in the interiors block, where the section concentrates on the aspects of passenger cabin design, human-machine interface design, and integration of circuit in ply panels.

Due to the delays the project has been subject to, this report includes the advancements performed within the project and described in D2.1, D5.1, D6.1, D8.2, D10.1 and D11.1. The work described by deliverables D6.2 and D7.1, which were expected to be released within the first year of the project before the deadlines were amended, will be included in the second version of this report, D12.6 “Report on year 2 CARBODIN demonstrators”.

5. CARBODIN Block 1: Car body shells

In Block 1, "Car body shell", CARBODIN will investigate the cost-efficiency and reliability of composite manufacturing technologies to dismantle the costs barrier preventing the market introduction of composite technologies. CARBODIN will enable a significant cost reduction by developing a new concept of modular tool capable of producing several parts with different geometries. Adopting this tool will eliminate the need to produce a new tool for each new part of the car body shell structure.

Block 1 has the following specific objectives:

- Develop a new concept of modular multi-material mould for re-use for several geometries, thus reducing time and cost manufacturing.
- Develop tools by a combination of technologies: conventional machining and 3D technology to minimise tooling costs.
- Introduce co-cured and co-bonded composite parts and develop multi-material integrated joints and inserts to reduce the number of steps in car body manufacturing and reduce the manufacturing cost and weight reduction.
- Develop new smart tooling for composite car body manufacturing by introducing in-mould sensors for OOA process control.
- Implement automation concepts for OOA process manufacturing for cost and time reduction.
- Develop and demonstrate intelligent sensor nodes capable of monitoring the car body conditions, and decision support tools using data generated from the sensing nodes to allow a predictive maintenance strategy.
- Manufacture, validate, test and evaluate number of steps reduction in car body part manufacturing by implementation of 3D printed tools and inserts that will enable the modularity of the process manufacturing and car body weight reduction

Block 1 is composed of WS1, WS2, WS3, and WS4. The following paragraph will introduce the work done within this first block at the level of WS2 and demonstrate how the project is working towards the achievement of specific WS objectives.

5.1. On-Board data processing

With WS2, CARBODIN has the aim of:

I. Develop and demonstrate intelligent sensor nodes capable of monitoring the condition of car body.
II. Develop intelligent decision support tools making use of the data generated from the sensing nodes to enable the realization of predictive maintenance strategy.
III. Reduce damage to car body by remotely monitoring its condition.
IV. Increase infrastructure availability by minimizing disruption on network due to faulty composite car body.

The ultimate objective is to be able to timely detect early stage and developing faults remotely to implement the best maintenance approaches. Furthermore, the sensors used to detect the faults will also provide feedback about crucial metal-composite interfaces, thus the sensor array will minimize the risk of catastrophic outcomes related to crucial joint fractures and car body parts

disposition.
Within WS2, CARBODIN also aimed to select the appropriate type of sensors to monitor the car's integrity and determine the technical specifications that the sensors need. To achieve the objectives a hybrid Structural Health Monitoring (SHM) technology with two different sensor arrays was selected to study how the data can be transferred to a processing server at low-cost, high reliability, and in a maintenance-friendly way. Ultimately, this study will allow minimising maintenance costs without a compromise to passenger safety.
Deliverable 2.1 "Selection of technology and development of on-board data processing pack" presents the work done within WS2. The project analysed how the use a dual network of sensors can detect the car body's structural integrity 24/7. The two networks work in parallel.
The first network consisted of nodes able to detect acoustic emission (AE) events from structural cracks and failures. AE is a well-established industrial monitoring methodology widely used for detecting composite failures. For this experimentation, the authors used the Mistras micro-SHM AE system, which has two channels for AE and two input channels that can be set up for any of the sensors shown in Figure 1.
The second network employed by the study comprises accelerometers, gyroscopes, and temperature sensors over a wireless network. This network produced good results in detecting abnormal vibrations leading to significant structural failures. It also successfully detected loose structural joints. The temperature network sensors can provide prompt detection of upcoming thermal events and even fire outbreak.

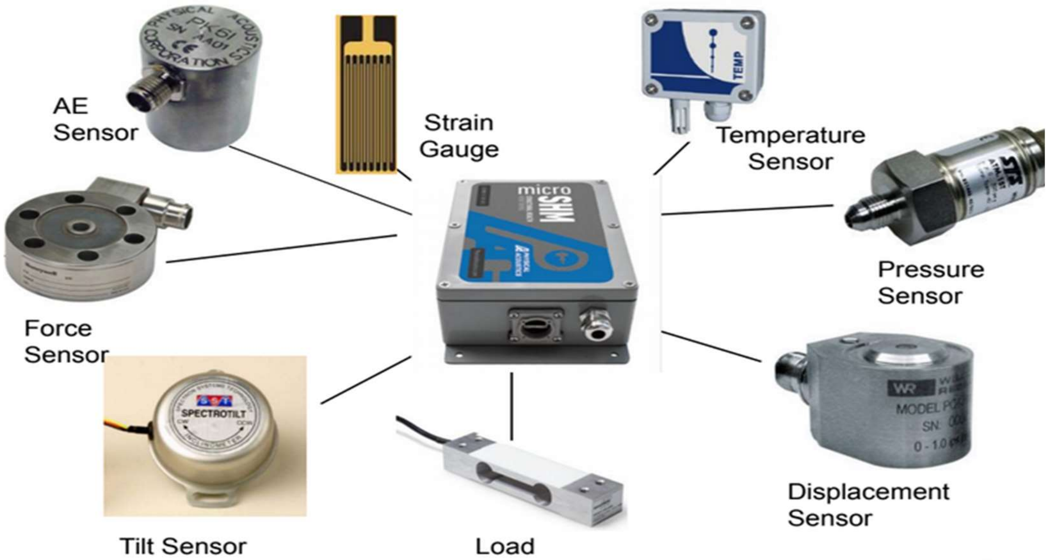


Figure 1. ***The central micro-SHM module surrounded by the peripheral ecosystem.***

The authors demonstrate that AE is an excellent, widely used technique to detect composite failure and fatigue. However, it is also characterised by excellent sensitivity and several features to differentiate failure modes. AE equipment proved to be robust, reliable, and able to use the latest wireless techniques to transfer data to a remote server for further processing, detection of flaws, and perform predictive maintenance.
The study proved that either the AE system or the low-cost and low-power network of Micro-Electro-Mechanical-Systems (MEMS) of accelerometer and gyroscope sensors have the necessary

sensitivity to detect minute vibrations on the surface of composite structures. This sensitivity could be significantly enhanced if the sensor arrays are properly fused with the car body to avoid poor mechanical coupling. Moreover, as the system can be equipped with sensors for temperature and humidity, the system can provide an alarm on possible fire outbreaks or composite softening.
The combination of the two measurement systems can produce exceptional results in monitorisation and machine learning-based predictive maintenance.
During the study, the authors performed three experiments to investigate Micro-SHM functionality and produce initial results. In the experiments, a composite plane with four holes, a pencil lead, and two sensors were employed, as seen in Figure 2. The composite plane had three holes between the sensor and the pencil lead break source, in addition to a fourth hole located the furthest from the sensor. The AE sensors R15a and R6a, which are shown in Figure 3, are designed to detect events around 150 kHz and 60 kHz, respectively.

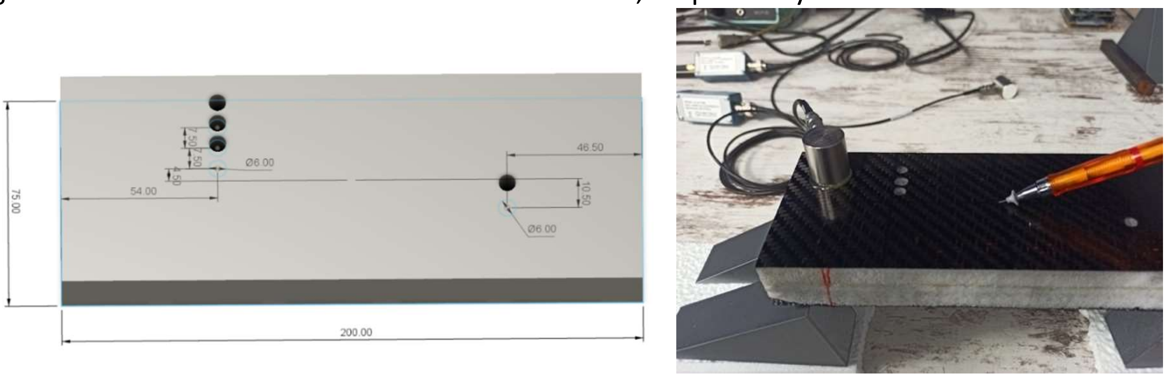


Figure 2. ***Drawing of the composite plane with four holes (left) and the test setup (right).***

Figure 3. ***AE sensors R15a (left) and R6a (right).***

The results showed a reduced energy and amplitude with the increase of the defects. Furthermore, the authors observed that the RMS value for all the experiments was satisfactory and that a higher variation occurred for the ASL metric with the R6a sensor experiments. These results are promising and from the work undertaken in this context two articles were published [1], [2].
Overall, the SHM approach consisted of a parallel twin system, with AE wireless devices covering

car-body areas requiring extreme sensitivity (central metal-composite joints parts, composite to wheels joints etc..), and along with wireless sensor-node network scattered and deployed across the car-body inspecting and covering large areas of composite parts like composite sidewalls and joints between composite sidewalls and car-body skeleton. Comprising the results from these two approaches and along with the addition of a Fibre Optic Sensor (FOS) network, the whole system provides an ever first case fusion of these state-of-the-art SHM technologies, supporting 24/7 of unparalleled SHM over the car-body structure. This is true because these 3 systems have been widely used in all sort of SHM cases with thousands of studies endorsing their fine monitoring capabilities, offering a plethora of structural features gathered across and along the car-body, all unique and independent, acting as inputs to advanced Machine Learning inferencing models advancing over failures and predictions.

Of course, no matter how good a system may be the underlying processing including the used Machine Learning models must offer the latest available technology elevating prediction levels, robustness on prediction, and failure detection accuracy. For each of the three aforementioned systems a different modelling approach was taken.

Regarding AE, a Deep Neural Network (DNN) was taken, with inputs statistical features; like kurtosis, variance, RMS retrieved from raw AE sensor outputs.

A similar approach was taken for the FOS system but instead of DNN a Long-Short Term Memory (LSTM) model was used, again with inputs retrieved rolling statistical features.

Regarding the accelerometer sensor-node network a more complex approach was taken mainly due to the fact of intrinsic low latency wireless connectivity, and node deployment across the car-body employing perhaps hundreds of nodes across a single car-body. In more detail, all nodes were spatially clustered with each cluster utilizing a rich set of state-of-the-art Machine Learning models, running in parallel and concluding to a final infer over possible failure and failure prediction, by merging models' inferences by using K-means clusterization. By this way, the outputs provide a rich set of information; especially if statistics is applied over K-Means results and thereby concluding in fine reliable failure prediction results. However, due to a delay in obtaining representative specimens that emulate car body structures, there is still significant work to be done before the end of the Work Package. Problems to be solved concern where exactly the sensors will be placed inside the car body, with what spatial density, and when, where, and which system will mostly be used on various locations of the car body.

Deliverable 2.2, which will be released within the second half of the project and will be included in Deliverable 12.6, will provide more information on the SHM and on-board monitoring solutions identified by the WS.

6. CARBODIN Block 2: Doors

Similarly to the work done in Block 1, in Block 2 of "Doors", CARBODIN will investigate the cost-efficiency and reliability of composite manufacturing technologies applied to the context of regional train doors. The project focuses on the development of modular tools to reduce the cost of production of composite parts of similar geometry. Moreover, CARBODIN will develop technologies to improve passenger comfort in the vicinity of the doors, ensure thermal and acoustic insulation, develop an accessibility ramp and gap filler and perform accessibility tests.
Block 2 has the following specific objectives:

- Develop the door leaf manufacturing process/technology accessible to the industry in composite materials
- Develop new modular tooling with high flexibility for geometry changes adaptation to reduce the manufacturing cost.
- Reduce the weight of the whole door system by enabling the use of composite material for the door leaves.
- Improve passenger's comfort by enhancing the acoustic and thermal behaviour of the door leaves.
- Improve passengers' comfort by eliminating accessibility barriers and other boarding and alighting operational complications.
- Reduce the NRC of the door leaf manufacturing process, making it versatile and flexible.

Block 2 is composed of WS5, WS6, and WS7. The following paragraphs will introduce the work done within this second block at a WS level, thus demonstrating how the project is working towards the achievement of specific WS objectives. However, it should be noted that the project could not perform certain expected activities due to the lack of inputs from complementary project PIVOT2.

6.1. Modular Tooling

Accessibility systems, particularly doors, are among the most critical and important systems integrated into rolling stock material. Through the years, the door systems have been in continuous evolution. The introduction of electric doors has greatly improved train accessibility while preserving the users' safety and integrity. Recently, developers have been focusing on ways to reduce the door systems' cost and weight while improving the "comfort" performance.
With WS5, CARBODIN aims to provide a manufacturing solution able to produce the composite door leaves and develop a modular mould with 3D-printed inserts able to produce two different geometries with the same tool. This innovative approach will allow employing one modular tool to manufacture diverse composite door leave geometries by vacuum infusion technology. The tooling solution considers parameters such as modular 3D inserts, versatile design, dimensional accuracy, surface roughness for the finished product, modularity, and low cost.
Deliverable 5.1 "Tooling technologies selection" presents the work done within WP5 "New tooling for Composite Door Leaves manufacturing". The study analyses, evaluates, and compares two different tool manufacturing technologies in terms of technical complexity, cost, surface finish, and modularity. This contribution is important as the employment of new manufacturing technologies and materials can significantly contribute to reduce weight in public transport system, thus lowering the energy consumption and the maintenance needs. Reduced weight can

be achieved using composites or additive printing in modern door manufacturing. However, these technologies are characterised by a lack of flexibility to adapt to different geometries, a lower efficiency manufacturing process, and a higher cost, which makes them dependant on the Non-Recurring-Costs (NRC).

In general, the use of composite materials in the railway sector (and especially in door manufacturing) is not as common as in other transport industries. This is due to the high cost of the tooling and the low volume of parts, compared to the other industries. Moreover, the railway industry is not very keen in “standardising” train components. The combination of a relatively low production volume and the constant changes in the design of the door leaves makes the door and train manufacturers hesitant and reluctant to the use of composite materials.

The study is characterised by the necessity to analyse and develop a tool with a low initial investment cost, but still be a flexible tool able to “absorb” changes and modifications. The development of such a tool could facilitate the acceptance of composite materials in the door manufacturing industry. Because of these characteristics, deliverable document D5.1 is crucial as it will allow creating an informed decision-making process that will define the appropriate tool technology able to produce a door leaf compliant with CARBODIN objectives.
To do so, the authors studied and analysed two door leaf manufacturing processes, which are shown in Figure 4.The first one was proposed by PIVOT2 and employs the Compression Moulding Process (CMP), while the second one was proposed by MASATS and takes advantage of the Vacuum Infusion Process (VIP).

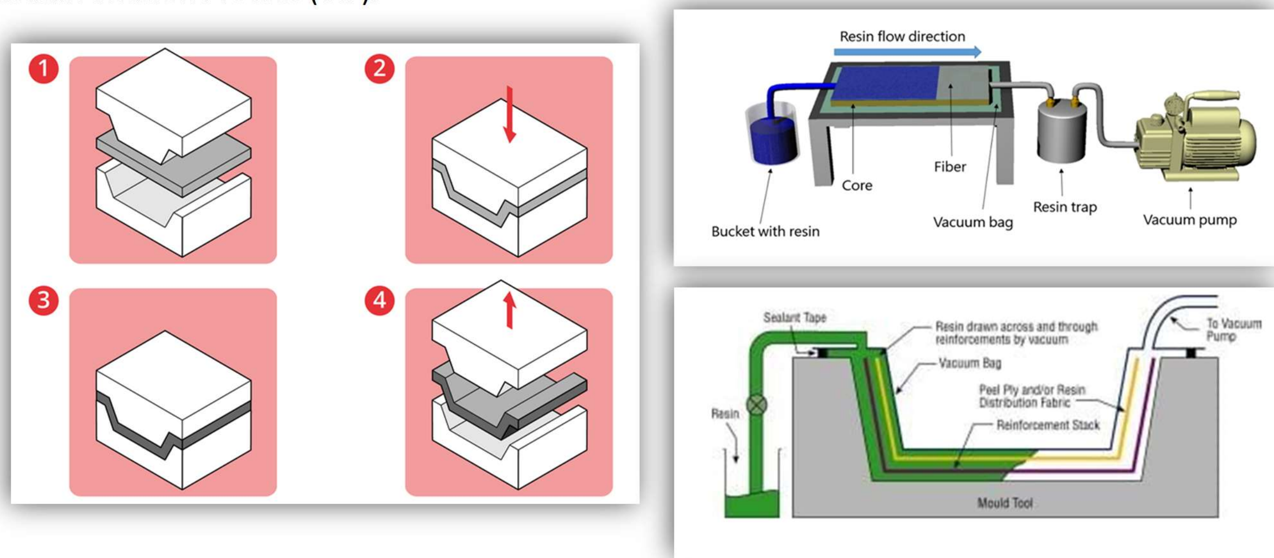


Figure 4. ***CMP principle (left) and VIP principle (right).***

The outcome of the study generated a qualitative comparison matrix able to provide conclusions and recommendations that will help in the selection of the tool technology (see Table 1 and Table 2). Among the parameters studied were the door leaf geometry, materials, modularity, and tool concepts.
The results are interesting because both the VIP and the CMP proved to be valid processes in the

manufacture a composite door leaf. Overall, the WS5 team considers feasible to design a modular tool using 3D inserts; however, the curvature and changes in the shape of the door limit and restrict the tool´s ability to adapt to different designs.

On the one hand, the authors highlight that CMP is more suitable for high production volumes and rates, but on the other hand the authors point to a high initial cost. Furthermore, CMP can produce higher quality products with a better finish and fewer demerits in production. Nevertheless, the main disadvantage is its significant initial investment, which constitutes a barrier to the introduction of composite materials in the door manufacturing industry. This disadvantage is significant considering the CARBODIN objectives.

Table 1. ***CMP characteristics*.**

SYNOPTIC TABLE: Compression Moulding Process

ITEM	CONCLUSIONS	QUALITATIVE EVALUATION		Comments
DOOR LEAF GEOMETRY	The CMP can handle the manufacturing of the proposed door leaf as it is presented in the PIVOT2 model (i.e., with no internal structure).	Overall dimensions	★★★★★	
		Symmetry	★★★★★	
		Curvature	★★★★★	
		Internal Structure	/	Not evaluated (refer to 5.1.2.2). If an internal structure is added then, multiple tooling units will be necessary
		Surface finish	★★★★★	
		Radii	★★★	
MATERIALS	No issues are foreseen with respect to the door leaf´s materials.	Skins	★★★★	
		Core material	/	Not evaluated (refer to 5.2.2.2). This information has not been provided by PIVOT2
		Curing cycle	★★★★	
MODULARITY	The modularity is mainly limited to the shape of the door specifically to the presence or not of a curvature. The presence of a curvature increases the tool costs and at the same time requires a different tool for different curvatures.	Length / width	★★★★	
		Curvature	★★	
		Window position / shape	★★★★	
		Inserts	★★★★	
TOOL CONCEPT		Moulds / holders material	★★★★	
		Inserts material	★★★★	
		Machinery	★★	
		Curing time	★★★★	
		Costs	★	

EXCELLENT ★★★★★ VERY GOOD ★★★★ GOOD ★★★ AVERAGE ★★ POOR ★

On the other hand, the authors stress the fact that VIP can produce an equally good surface quality product with a much lower initial investment expenditure, as the tool itself could be made of composite materials. The process is also more suitable for the railway industry, as it is more oriented to relatively low production volumes and rates. However, one drawback of the VIP process is the requirement of a more extensive preparation period, and the higher susceptibility to production demerits.

Table 2. ***VIP characteristics.***

SYNOPTIC TABLE: Vacuum Infusion Process

ITEM	CONCLUSIONS	QUALITATIVE EVALUATION		Comments
DOOR LEAF GEOMETRY	The VIP can handle the manufacturing of the proposed door leaf skins	Overall dimensions	★★★★★	
		Symmetry	★★★★★	
		Curvature	★★★	
		Internal Structure	★★	
		Surface finish	★★★★	Only to one side of the surface
		Radii	★★★	
MATERIALS	No issues are foreseen with respect to the door leaf´s materials.	Skins	★★★★	
		Core material	★★★★	
		Curing cycle	★★★★	
MODULARITY	The modularity is mainly limited to the shape of the door specifically to the presence or not of a curvature. The presence of a curvature increases the tool costs and at the same time requires a different tool for different curvatures.	Length / width	★★★★	
		Curvature	★★	
		Window position / shape	★★★★	
		Inserts	★★★★	
TOOL CONCEPT	The tooling for the VIP is quite simple and cost effective, which keeps the NRCs low. It does not require neither expensive moulds nor the use of a high capacity hydraulic press.	Moulds / holders material	★★★★	
		Inserts material	★★★★	
		Machinery	★★★★★	No need for big hydraulic press with heated moulds
		Cost	★★★★	
		Curing time	★★	

EXCELLENT ★★★★★ VERY GOOD ★★★★ GOOD ★★★ AVERAGE ★★ POOR ★

In conclusion, the WS5 members identified VIP as more appropriate than CMP, based on the required number of units to be produced according to PIVOT2 inputs and CARBODIN objectives.

6.2. Thermal and Acoustic Isolation

Currently, almost all door leaves used in regional trains employ insulation material in the void between the two metallic skins. This material can be a honeycomb matrix, high-density foam, or rockwool. However, every material currently has limitations in improving noise attenuation and reducing the heat transfer from the outer to the inner surface. The lack of a “perfect” airtight door closure is one of the main factors that influence noise levels inside the train due to its central and perimetral rubber seals.
Within WS6 “Solutions for thermal and noise reduction in the neighbourhood of the door” CARBODIN aims at achieving significant improvements in the current state-of-the-art and

materials employed in this context. The overarching objectives of WS6 are to develop passive solutions to reduce the noise in the vestibule in the vicinity of the doors, and to recommend active solutions. The target for WS6 is to provide solutions for the passenger comfort in two areas. From the acoustic point of view, passengers should be able to use their cell phone in the vicinity of doors, while from the thermal point of view, the door isolation should provide stable temperature in the area.

Deliverable D6.1 "Report on materials and strategies for thermal and acoustic isolation" presents the work done within WS6. The WS contributes to the goal of increasing passenger comfort in regional trains in particular regarding thermal and acoustic conditions in the vicinity of the doors. The WS aims at finding (i) the right combination of materials to improve thermal features, (ii) the right combination of geometry and materials to improve acoustic features, and (iii) the optimum conditions and requirements for efficient and time lasting sealing technology. Furthermore, WS6 contributes to reach the thermal and acoustic targets defined by the PIVOT2 project, such as noise attenuation by 35 dB in the short term and 38 dB in the long term as well as a heat transfer coefficient reduced below 3.3 W/m2K. Lastly, the weight limit of 16 kg should not be exceeded.
The researchers introduce a new concept and investigate the ability of the concept to fulfil the thermal and acoustic objectives of the project. This concept is based on recent scientific and practical achievements in other industries, such as aviation, and is proposed for application in regional train cars. The concept, composed of glass fibre reinforced polymer (GFRP), ABS, gluing tape and mineral wool, has been subject to tests evaluating its thermal and acoustic performance.

The authors investigate the application of a specific design variant in a section of a MASATS regional train door, where they apply acoustic and thermal performance calculations. The results demonstrate that the concept can be successfully applied to the intended structures. The WS identified that the objectives regarding thermal dispersion can be achieved when composite materials or polymers are used, under the condition that metallic thermal bridges are avoided. Within this context, the door weight reduction requirement can be addressed with the use of composites or polymers.
On the other hand, the WS identified that the proposed concept can contribute significantly to reach the acoustic objective in the regional train doors and in the vestibule walls. As such, the concept can be fruitfully applied to increase the passengers’ comfort in regional trains.

In conclusion, the authors recommend continuing the work towards a prototype door made of laminates and polymers. Both solutions are expected to fulfil the project objectives and leave the constraints of the door weight and strength requirements to other work packages.

7. CARBODIN Block 3: Interiors

Within Block 3 “Interiors”, CARBODIN will develop modular and aesthetic interior designs and layouts, which will be characterised by low cost and a rapid uptake. The project will also identify new human-machine interactions for future cabins and integrate low volt circuits in panels to increase reliability

Block 3 has the following specific objectives:

- Develop modular and aesthetic interior designs which fit to the new fixation system concept.
- Create a configuration tool to reduce the time to market and the prototype costs by using virtual reality.
- Design flexible low-cost manufacturing tools for interior components.
- Perform a European survey to identify possible human-machine interactions like gesture, sound, and voice for the driving cabin.
- Specify and develop low volt circuits for the implementation in wall, roof, and floor.

Block 3 is composed of WS8, WS9, WS10, and WS11. The following paragraphs will introduce the work done within this third block at a WS level, thus demonstrating how the project is working towards the achievement of specific WS objectives.

7.1. Passenger Cabin Design

Deliverable 8.2 “Technical analysis” summarises the results of activities performed within WS8 “Modular Interior’s concepts and virtual immersive interior design configurator tool”, and more precisely in tasks 8.6, 8.7, and 8.8. With WS8, CARBODIN aims to: (i) develop modules for ambiences, lighting, and accessories; (ii) include the development of new interiors design with quick fixation system from PIVOT2; (iii) include competitive cost validated by an economic study; (iv) perform design studies and deliver physical mock-ups; and lastly (v) develop a configurator tool using new immersive technologies to enhance several layouts.

The work undertaken within WS8, and presented in D8.2, provides an overview of existing plug-and-play systems used in various applications. These applications can differ from their future field of application. This study aims to support the WS8 objective of developing various interior designs for future trains by taking the passengers' needs into account. Furthermore, it also contributes to the TD1.7 objectives of:

- Increasing the reliability by the facility of equipment change related to the travellers.
- Providing an improved customer experience, offering the possibility to add easily new services or new spaces.
- Increasing capacity “on demand” to adapt the train to the need.
- Developing modular and plug and play solutions.

In the first step, the authors targeted a high number of interesting plug-and-play systems, which matched the criteria identified within the complementary project PIVOT2, namely:

- Easy and fast usage,
- Systems that can be used to connect a kind of surface plate with a basic structure,
- If possible, a system for strong connection,
- If possible, the selected systems should create a mechanical and/or electrical connection.

Criteria such as the thickness of the surface plate or standard adoption were not considered. Additionally, to gather as many systems as possible, the study employed a high number of search words in three different languages: English, German, and Spanish. This first step allowed the authors to identify 61 different plug-and-play systems.

In the second step, the study evaluated the identified plug-and-play systems using 14 new criteria, showed in Table 3.

Table 3. ***Criteria for the evaluation of identified plug-and-play systems.***

No.	Criteria	Reason for the criteria
1	No irregularities at any given point on the floor in the walking areas, except it has a maximum height of 3 mm	To prevent the passengers from stumbling
2	Creates a strong contact between the surface/ plate and the basic structure (mechanical)	Intended for the complementary project
3	Creates an electrical contact between the surface/ plate and the basic structure	Intended for the complementary project
4	Tested in accordance with the specifications referenced in EN 45545-1, 2 and 3 – fire behaviour properties – for example in the case of flammability, smoke opacity, and toxicity	To ensure the safety standard by preventing fire or reducing the negative effects due to a fire
5	Surface of the plates are easy to clean and maintain	It must be clear from the surface of the plates whether cleaning and maintaining should be taken into account
6	Resistant to humidity, water, cleaning products, and disinfectant products	It must be clear from the surface of the plates whether various products had contact with the systems
7	Resistant to wear and aging	A high lifetime is desirable
8	Dimensional stability or dilatation (e.g., after exposure to heat, water, chemicals, compression, etc.)	To guarantee a repeated possibility for assembling and disassembling
9	System releases no odours	To keep odours of any kind away from the passengers
10	No usage by passengers possible (without additional tools)	The passenger should not be able to remove the floor or parts of the floor
11	No gap between the surface plates necessary	Any kind of gaps will allow fluids to reach the subjacent level
12	Ability to disassemble only one surface plate without removing the others	Intended for the partner project
13	Assembling and disassembling is possible without damaging the surface/ plate	Reducing costs, i.e., if maintenance in the subjacent level is necessary
14	Withstand vibrations in railway vehicles (for example DIN EN 61373)	The plug-and-play systems must resist the vibrations, which are normal in railway vehicles

These criteria were only used for the plug-and-play systems and not for the types of systems. Moreover, for the evaluation, it was presumed that the surface plates would be assembled and disassembled with a pneumatic system, showed in Figure 5.

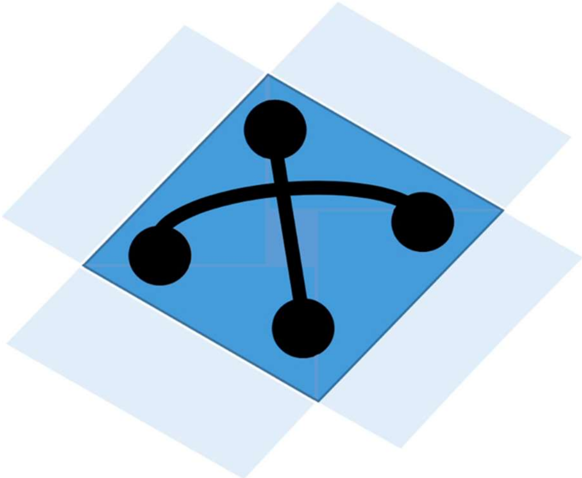
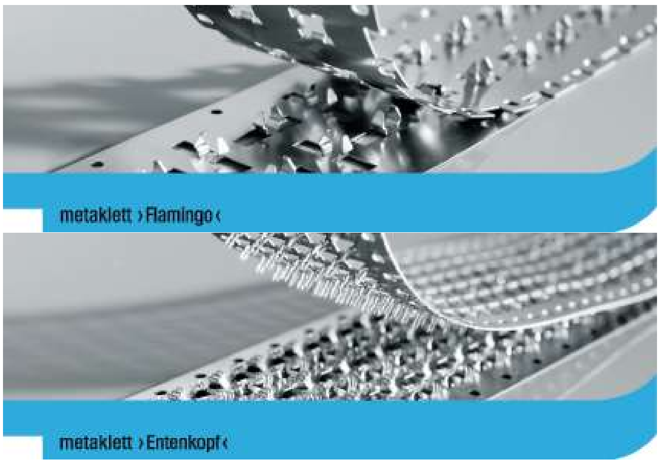


Figure 5. ***A sketch of the disassembly a surface plate.***

Upon recommendation from the complementary project PIVOT2, the WS aimed at identifying a system able to provide both a strong mechanical connection and an electrical connection. However, as this was not possible due to the type of systems available, the mechanical aspect was separated from the electrical aspect. The following section lists ten plug-and-play system identified for mechanical connection and five systems for the electrical connections.

Amongst the systems for mechanical connections, the Metaklett system[1], shown in Figure 6, classified first. The Metaklett system is available in three different versions, which offer various benefits and fulfil most criteria. Furthermore, the stresses vary based on the version and the loading angle.



[1] 1 https://www.metaklett.de/en/technologie.html

Figure 6. ***Three different versions of the Metaklett system.***

The main benefit of this system is that the surface plates can have any possible geometry, even though they have to be flexible. Another benefit is that it does not require a connection to the surface of the plates and there is no need for a gap between the plates. Therefore, the cleaning procedure can be fast and the resistance of the system depends only on the plates and not on the Metaklett system itself. This system provides the possibility to assemble the surface plates in various directions, if the system “Entenkopf” or “Hybrid” are used. Additionally, the system can create a strong connection, as recommended by complimentary project PIVOT-2. Both lead to a flexible and multifunctional plug-and-play system, which can resist local vibrations.

The second plug-and-play system identified correspond to the snap coupling system[2], as showed in Figure 7. This plug-and-play system possesses a major limitation: assembling and disassembling is possible only if the plates next to the specific plate are removed before. Additionally, it requires accessibility to both sides of the plate, where the snap coupling is implemented. This system is unsuitable for plates; however, it can be utilised for seats or tables, but mechanical tests will be necessary due to the lack of information of how strong the connection is.

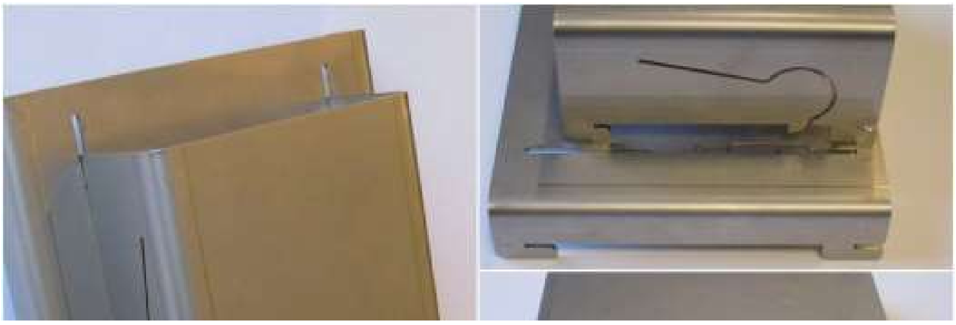


Figure 7. ***Snap coupling system of metal sheets.***

The third plug-and-play system identified is the TIGA-Fassaden system (shown in Figure 8), which provides a strong connection between boards and the basic structure. This system presents two major limitations. Firstly, a large gap between the boards or the panels is necessary. Additionally, the assembling and disassembling of a specific board is possible only if the previous boards are assembled or disassembled. Both limitations can cause difficulties when cleaning and replacing the boards, which is a major disadvantage if this system is used for the floor.

[2] https://www.blechnet.com/blechteile-mit-haken-ermoglichen-eine-schnappverbindung-a-820219/

Figure 8. ***TIGA-Fassaden system[3].***

The fourth plug-and-play system analysed is the so called easy-click system[4] used for isolator gloves (see Figure 9), which allows a fast assembling and disassembling.

Figure 9. ***Easy-click system.***

Within its specific application area, it guarantees a chemical resistance based on the employed materials. It also permits to assemble and disassemble each plate independently. Furthermore, the presence of gaps between the plates is not necessary, which facilitates cleaning the surface. The main disadvantage of this system is that it does not provide a strong connection between the basic structure and the panels. That means this system should only be used in particular for the panels, but not for e.g. seats.

The fifth plug-and-play system identified is the SNAPLOC[5] (see Figure 10), which is nearly equal to the sixth-ranked system, which is a snap coupling for plastic components[6] (see Figure 11). Both systems provide a soft connection only and not the intended strong connection, which is necessary for chairs, for example. They allow assembling and disassembling of single panels without

[3] https://brunsholz.com/de/produkte/brunsholz-tiga.html
[4] https://www.carloerbareagents.de/produkte/isolatortechnik/zubehoer-isolatortechnik/easy-klicksystem-handschuhwechsel/
[5] https://www.boellhoff.com/de-en/products-and-services/special-fasteners/decoupling-fasteners-snaploc.php
[6] http://files.hanser.de/Files/Article/ARTK_LPR_9783446413221_0001.pdf

removing the other ones. Depending on the panels' structure, a chemical resistance of the plug-and-play system is necessary, which can cause a problem in both cases due to material limitations of the usable plastic. Before they can be implemented as connecting systems, vibration tests, load tests, and additional material tests should be carried out.

Figure 10. ***SNAPLOC*.**

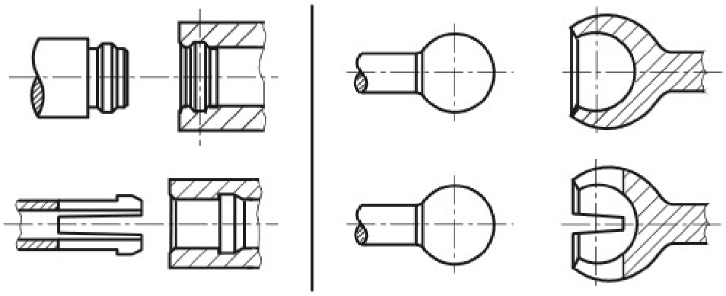


Figure 11. ***Snap coupling for plastic components*.**

The WS ranked seventh a button system[7] (see Figure 12), typically used to connect soft and flexible materials. The main advantage of this system is that no irregularities on the surface plates are necessary and there are no gaps between the plates, which facilitates the cleaning process of the plates. However, a strong connection between the surface plates and the basic structure (e.g. to secure chairs) is not possible. The implementation onto inflexible panels requires tests. Nevertheless, this system is applicable only in case of soft connections.

Figure 12. ***Button to connect two components*.**

[7] https://www.prym.de/p/naehfrei-nachfuellpackung-fuer-390117-perlkappe-12mm-13901220

The eight-ranked system consists of a seismic resistant cabinet door push latch[8], shown in Figure 13. The system unlocks only when someone pushes the latch, which enables an easy assembling and disassembling of panels. This represents also one of the main disadvantages of the system, due to the fact that passengers are also able to disassemble the panels. Furthermore, this system does not provide a strong connection as wished by the complementary project. This system is able to fulfil its task despite of vibrations.

Figure 13. ***Seismic resistant cabinet door push latch.***

The WS ranked ninth the connection system for floor panels[9], shown in Figure 14. The main disadvantage of this system is the non-existing connection to the basic structure, which is why this system cannot be used for the sought purpose. This means the system does not provide even a soft connection. However, the system can resist chemicals if the materials are selected properly.

Figure 14. ***Connection system for floor panels.***

Lastly, the system which ranked tenth consists of a pipe plug system[10] (see Figure 15), which is not capable to withstand vibrations in trains. Furthermore, assembling and disassembling requires accessibility to the connecting pipe plug system, which has to be taken into account during the construction phase.

[8] https://worksafetech.net/seismic-resistant-cabinet-door-push-latch-4-latch-minimum/
[9] https://www.bricoflor.de/fortelock-home-decor-2110-wood-medium.html
[10] https://rohrstecksysteme.de/

Figure 15. ***Pipe plug system.***

Amongst the systems for electrical connections, two systems ranked first with an equal evaluation: a two-pole neoprene moulded connector system[11] (see Figure 16) and a cage clamp system[12] (see Figure 17).

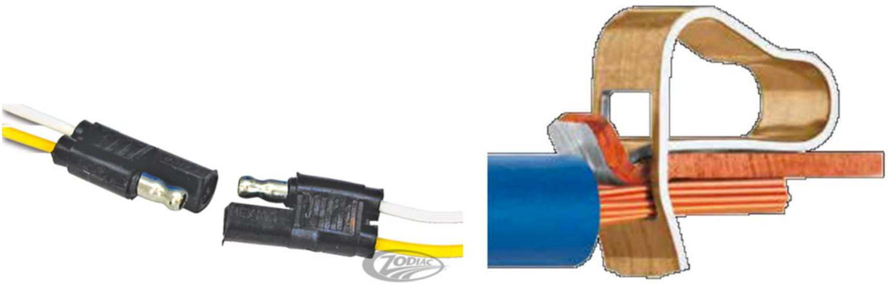


Figure 16. ***Two suggested systems for electrical connections. Two-pole neoprene moulded connector system (left); cage clamp system (right).***

Both systems should be considered for the development of the surface plates. However, due to the way the cables are implemented on the floor, it is not possible to employ either of these two suggested systems, as they both need free space to be connected by hand. Possible solutions could be to employ a long cable or develop an alternative system using magnetic self-mating connectors[13]. Nevertheless, additional tests are needed to check if a stable magnetic connection is possible during the train vibrations.

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[11] https://catalog.zodiac.nl/de/04-elektrik-beleuchtung/kabel-kabelverbinder/2-polige-neopren-verschweisste-steckverbindungen/2-polige-neopren-verschweisste-steckverbindungen-1161

[12] https://www.wago.com/infomaterial/wago_ebook/60337817/html5/index.html

[13] https://www.rosenberger.com/0_documents/de/catalogs/ba_medical/MI_Magnetic_Products_Flyer_EN_2015.pdf

Figure 17. ***Magnetic self-mating connectors.***

A third possible plug-and-play system consists of a plug system for lamps[14], shown in Figure 18. This system is used to connect multiple lamps, though direct accessibility is required to connect the system by hand. Like the previous two systems, accessibility is lacking thus it cannot be employed within the scope of the WS. However, it can provide a connection for low voltage circuits, which will be implemented into the panels.

Figure 18. ***Plug system for lamps.***

The last system identified (see Figure 19) consists of an IDC-terminal.[15] This system has been specifically developed to connect painted wires, and it creates a stable connection by removing the insulating paint. The connection is stable against vibrations, but further tests are required. However, if the system is reconnected on a different position, the system leaves a stripped wire, which represents a safety risk.

Figure 19. ***IDC-terminal.***

[14] https://www.led-lights24.de/LED-Unterbauleuchte-Mecano-15cm-24V-DC-150lm-25W-Stecksystem-EEK-A-

[15] https://smartconnect.iwis.com/de/iwis-technologien/idc

7.2. Human-Machine Interface Design

With WS10, CARBODIN aims to identify the expectation of train drivers and other railway operator staffs about Human-Machine Interface (HMI) in future cabins. The ultimate objective is to provide new data necessary to design Innovative Driving cabins. WS10 aims to achieve this objective through a European survey - that will consider human factors as input and output sensors – to define a common new HMI standard, which uses gesture, sound, and voice input/output. WS10 results will allow to select new technologies and new uses of the driver's cabin and contribute to the design of Cabin & Driving 2030. Furthermore, the bank of sounds and gestures identified within WS10 will be used to develop a virtual mock-up with immersive technology within the complementary SHIFT2RAIL project PIVOT-2.

Deliverable 10.1 "State of the Art of HMI in transport industries" presents the work done within WS10. The project provides a synthesis in cognitics (cognition and automation), in human factor, and return on experience in different industries (aeronautics, car, aviation, sea transport) for HMI design. To reach WS10 objectives, this study provides an overview of Human Machine Interfaces (HMI) design and command systems in commercial or experimental operation and simulators across all transports modes. Special focus was dedicated to qualifying new technologies potentially applicable in future train cabins, such as visual displays and haptic shared controls.

The authors analyse the HMI systems developed by manufacturers of vehicles outside railway field such as trucks (2 systems), cars (3 systems), and ships (1 system). The identification of technologies already in use or to be experimented has been undertaken with specific regard to how these technologies can support or substitute the driver towards autonomous driving. An overview of the investigated relevant solutions applied to vehicles outside the railway field is collected in Table 4.

Table 4. ***Characteristics of the analysed technologies.***

	Name	System	Automation	Sector
Trucks	MAN PLATOONING (DB SCHENKER)	- Driver assistance - Control systems	Driver always keeps his hands on the wheel	Road Freight
	HIGHWAY PILOT (DAIMLER)	Autopilot for trucks	Driver can choose an autonomous driving mode	Road Freight
Cars	AUTOPILOT 2.5 (TESLA)	Navigate on autopilot	Driver always keeps his hands on the wheel	Road Passengers
	DRIVE PILOT (DAIMLER-MERCEDES)	Fall-back-ready user	Driver can choose to leave an autonomous driving mode by steering, braking, accelerating or manually switching	Road Passengers
	iNEXT-COPILOT (BMW)	Ease iNEXT mode	Driver can choose an autonomous driving mode with a voice command or by touching a logo	Road Passengers
Ships	THE FALCO (FINFERRIES and ROLLS ROYCE)	Full automation	No human intervention, functional, and easy-to-use human-machine interface with ergonomically placed control levers, touch screens by which systems can be called up and controlled	Water Freight and Passengers

Furthermore, the authors analyse the simulators developed for various transport systems, such as rail (4 systems), cars (3 systems), aviation (4 systems), and integrated (1 system) simulators. The analysis of simulators is identified as an essential starting point for design development. Moreover, simulators allow to test in advance the applicability of the physical elements before the construction and obtain precious information for the future driving design and testing costs reduction. Table 5 shows a summary of the investigated simulators.

Table 5. ***Characteristics of the analysed simulators.***

<table>
<tr><th></th><th>Name</th><th>System</th><th>Automation / Characteristics</th></tr>
<tr><td rowspan="4">Rail simulator</td><td>PSCHITT-RAIL</td><td>6 degrees of freedom motion system</td><td>- Movement capture system
- Eyes tracker
- Physiological measurement sensors</td></tr>
<tr><td>SPICA RAIL</td><td>Supervision platform</td><td>Gradually increases disturbances to evaluate human behaviours</td></tr>
<tr><td>OKTAL SYDAC</td><td>Exact replicas of the cab</td><td>A realistic driving experience</td></tr>
<tr><td>IFFSTAR-RAIL</td><td>Rail traffic supervision simulation platform</td><td>- Driving and traffic simulator
- Test bench</td></tr>
<tr><td rowspan="3">Car simulators</td><td>IFFSTAR TS2</td><td>Fixed-base cab simulators</td><td>Impact of internal and external factors on driver behaviours and HMI</td></tr>
<tr><td>NDIVIA DRIVE</td><td>Open platform</td><td>Interfaces between the environment, vehicles, sensor models, and traffic scenarios</td></tr>
<tr><td>VRX-2018</td><td>Autonomous vehicle simulator</td><td>- Allows the user experience how the cockpit’s HMI feels
- Allows developers to test next-generation sensors</td></tr>
<tr><td rowspan="4">Aviation simulators</td><td>CAE 7000XR</td><td>Full-flight simulator</td><td>- Adapts to operators' needs
- Easy access to advanced functions</td></tr>
<tr><td>CAE 3000</td><td>Helicopter flight simulation</td><td>Realistic simulation of normal and particular/dangerous flight conditions</td></tr>
<tr><td>EXCALIBUR MP521</td><td>Capsule with a six-axis motion system</td><td>- Data Editor-Graphical User Interface
- Visual and instrument displays
- Touch control panels
- Hardware flight controls</td></tr>
<tr><td>ALSIM</td><td>High performance visual system</td><td>Flight training and interchangeable cockpit configuration</td></tr>
</table>

	iVISION	- Human cockpit operations analysis module - Semantic virtual cockpit - Virtual cockpit design environment	Design and validation of human-centered aircraft cockpits
Integrated simulators	MISS RAIL	Train/car simulator	- Automated driving assistance - Allows developers to design accident scenarios combining pedestrians - Human factor control technologies

D10.1 includes a comprehensive literature review on the performances of supporting tools for driver assistance. The study compares studies on factors that could improve or lower drivers' performance, such as dieting or fasting, auditory alarms, visual or audio-visual displays, etc. Furthermore, the study analyses technical support systems that assess cognitive processes, such as perception or problem-solving. These systems involve eye trackers, facial recognition systems, or heartbeat sensors.

Lastly, the contribution identifies the technological solutions capable of controlling devices by gestures currently present on the market and carried out a SWOT analysis of three gesture control technologies, as shown in Table 6.

Table 6. ***Strengths-Weaknesses-Opportunities-&-Threats analysis of three gesture control technologies.***

Name	Kinect	Leap motion	Myo bracelet
Strengths	- Body motion identification - Development kit available	- Hand and finger movement identification - Low price - Lightweight device - Development kit available	- Gesture detection only from the bracelet wearer - Lightweight device - Development kit available
Weaknesses	- Operational difficulties when only a limited space is available - Possible interference between a movement and the detection sensor	- Deep training required - Possible interference between a movement and the detection sensor	- Limited number of identified movements - Deep training required
Opportunities	If gesture control with facial or voice recognition for security goals are combined.	If the use of infrared light and of cameras for security goals are combined.	If physiological detection as heartbeat with gesture control for security goals are combined.
Threats	Undefined gesture control intrusion recovery process	Undefined gesture control intrusion recovery process	Undefined gesture control intrusion recovery process

From the work undertaken in this context, a publication on the international scientific journal Machines has been published [3], which is a proof of the high transferability of these results.

In the conclusions, document D10.1 identifies all the investigated systems' Technology Readiness Levels within the following range:

- TRL 7 – System prototype demonstration in operational environment.
- TRL 8 – System complete and qualified.
- TRL 9 – Actual system proven in operational environment.

As such, they must all be considered in view of potential applications in the cabin driver design, considering that the expected Technology Readiness Levels (TRL) in the CARBODIN project are variable in the following range.

- TRL 5 – Technology validated in relevant environment.
- TRL 6 – Technology demonstrated in relevant environment.
- TRL 7 – System prototype demonstration in operational environment.

The next step is to select performance indicators to assess the functional affordability of specific driving-related actions by conducting a survey among train drivers and crew. In particular, the next task will consider human factors and their limits regarding technological supports that monitor and assist when driving.

7.3. Integration of Circuit in Ply Panel

With WS11, CARBODIN aims to integrate new functionalities - such as low volt printed circuits - in composite panels that provide electricity to passenger lights and electronic device charging points. Panels with low voltage printed circuits facilitate an efficient, easy, and aesthetical modularity-in-use. The ultimate objective is to reduce the Life Cycle Cost (LCC) and increase the attractiveness, comfort, and ergonomics of the interiors of car bodies. WS11 aims to achieve these objectives through a modular production technology based on printed flexible electronics integrated onto the train car body panels. Deliverable D11.1 "Ply specifications plan" presents the work done within WS11. The project focused on alternatives, proposals, and sketches of possible electric and electronic distributions, electric connection to the main power source, interconnections possibilities between panels, and alternatives.

To address the challenges outlined by WS11, the study identified several critical points regarding structural and technological aspects. Within the structural elements, the deliverable highlights five criticalities, in the union system between panels, in the electrical connection between the panels, in the electrical connection between the foil (printed circuit) and the train's electrical network, in the possible solutions to fix the actuators (light, USB connector and power outlet) to the panel, and in the separation distance from the panel to the train structure.
Furthermore, the deliverable highlights six criticalities from a technological perspective related to how to fix the actuators to the printed circuit foil, connect the actuators to the printed circuit tracks electrically, and fix the printed circuit foil to the panel. Other criticalities include the printed circuit tracks distribution, the substrate for the printed circuit foil, and the printed circuit itself, the functional ink on the substrate.
The study provides the following proposals, which address the problems of panel interconnection, power distribution, and power supply tracks conductive material.

Panel Interconnection

The possibility of using the current rail panel clamping method and technique has been identified as influential in achieving cost reduction when implementing the new design panels. The authors put forward two proposals to achieve connection between the panels, as shown in Figure 20.

- Proposal 1. **Direct Contact**: if a direct contact point is present between neighbour panel surfaces, conductive material could be added on both contact surfaces, thus connecting both panels' power supplies.
- Proposal 2. **Plug connector**: if there is no direct contact, but there is a small separation between panels, hybridisation of a 'male' connector would be performed on one of the panels and a 'female' connector on the neighbouring panel. Plugging these connectors, the power supply lines of both panels will be unified.

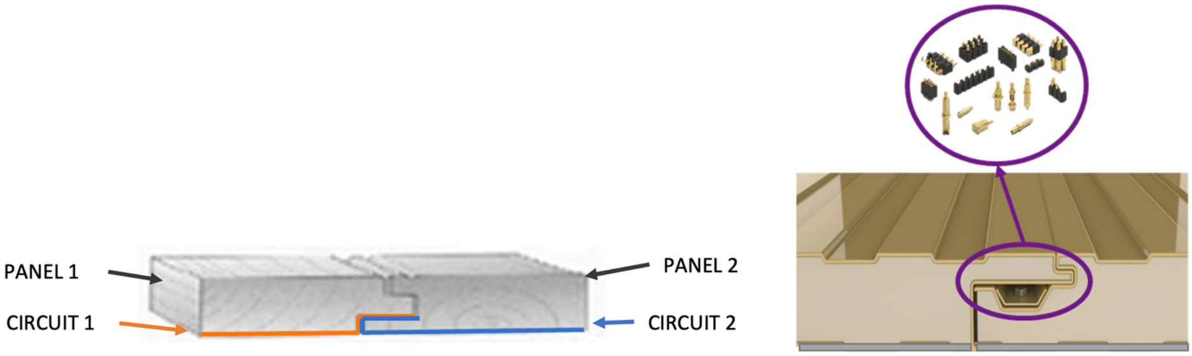

Figure 20. ***Direct contact panel interconnection (left); Plug connector for panel interconnection (right).***

Power distribution

The study identified three proposals to route the power supply lines, as shown in Table 7.

- Proposal 1. **Independent power supply tracks** composed of three power lines (5V DC, 24V DC, and 220V AC), each of them would deliver power to a different asset. However, this proposal was identified as possibly too complicated for the train's actual power supply system, mostly based on batteries and distribution of 110V DC.
- Proposal 2. **Curved 220V AC power supply tracks** composed only of one power line (220V AC). The male and female connectors of each panel will be mounted on pads placed near the edge of the panel so that adjacent panels can be coupled and share the power line. Power lines could be parallel to each other, but not necessarily.
- Proposal 3. **Straight 220V AC power supply tracks** follow the example of proposal 2, with the exception that power supply lines would be parallel to each other and symmetrical to the central latitudinal or longitudinal axis to the panel.

Table 7. ***Advantages and disadvantages of proposals identified for power supply lines.***

Power distribution	Advantages	Disadvantages
Proposal 1	- It allows for simpler electronic circuits.	- A possible complication when power supply is converted and distributed.

Proposal 2	- The internal wiring of the panel is simple. - Flexible power line routing is adaptable to the panel geometry.	- Wiring design may increase its difficulty and become more expensive. - All assets would require a 220V AC power input.
Proposal 3	- Parallel routing allows for shorter and cheaper wiring.	- Designed to work only with flat panels and without obstacles.

Conductive material of power supply tracks

The authors identified three proposals to replace the internal wiring power supply system currently in use with more efficient design solutions. Their advantages and disadvantages are shown in Table 8**¡Error! No se encuentra el origen de la referencia.**.

- Proposal 1. **Functional Inks**: functional ink (with a base of conductive material) might be printed with an additive technology on a flexible substrate and later fixed on the panel through adhesives.
- Proposal 2. **Polyimide-Copper**: a laminated composite formed by a thin layer of copper over a Polyimide substrate might be fixed to the panel with an adhesive. The conductivity could be higher than in proposal 1, depending on the functional ink used in that case. An example is shown in Figure 21.
- Proposal 3. **Copper adhesive tape**: it is a proof of concept to contrast the performance of proposal 2, due to its similarity in physical and material properties. It is characterised by its ease of use, relatively low cost, and malleability. However, it presents a crafted installation process that cannot be industrialised at this time.

Table 8. ***Advantages and disadvantages of proposals identified for conductive material.***

Power distribution	Advantages	Disadvantages
Proposal 1	- The additive process does not produce waste material. - A wide variety of substrates and functional inks are available to print on.	- There is a higher electrical resistance than regular wire. - Industrial functional ink printing processes are at an early stage of development.
Proposal 2	- The industrial processes to develop polyimide/copper composites films are well known. - The electrical resistance is very similar to that of copper wire. - Theses conductive films conventionally allows component soldering.	- The process generates a considerable amount of waste material. - The adherence between polyimide and other surfaces is difficult.
Proposal 3	- Fast prototyping system and development of a proof-of-concept (PoC) - Acceptable electrical resistance	- Tape can be peeled off. - The electrical material deteriorates quickly.

		- An industrial manufacturing process is not yet available.

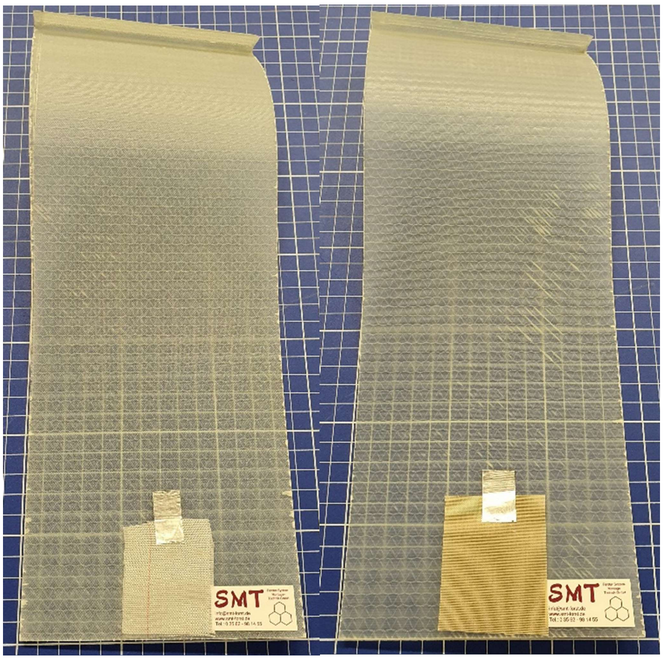

Figure 21. ***Two different laminates with three different surface structures to integrate low volt circuits on curved interiors.***

The conclusions reached after the study in the three differently focused areas are the following:

Power Levels and power line distribution: To simplify the design and maintain the maximum flexibility within different wall panels, it is strongly advised to distribute an AC power supply line (230VAC) and DC power supply line (110VDC) separately in independent and custom designs adapted to the panel morphology. This approach enhances the power supply interconnection between panels, simplifying the plug and play feature, and probably reducing cost. This option also allows for a less restrictive design in terms of placing the consumption points (wall outlets, lighting, etc.) around the panels.

Functional inks, substrates, and Polyimide/Copper films: Copper inks and silver inks have been considered, as well as different materials for substrates. However, to determine which combination of ink and substrate fits best for this purpose, more research and investigation will follow in the next months. Furthermore, to determine the best combination was out of scope of the *Book of Ideas* presented in deliverable document D11.1. If none of the studied combinations result good enough, then the solution proposed for the case under study can be Polyimide/Copper foil, which was one of the options presented.

Mechanical disposition of the panel and the car body: Interaction between the exterior wall panels design and power supply conductive foils design in the interior is a priority. It will determine the possible outlets or connectors that can be used in the conductive foils' side. Also, the position of the windows or other barrier elements can be determinant for the final conductive foil design. If we choose one final solution for the conductive foil disposition at this early stage, then we would strongly restrict the mechanical design of the panels.

8. Conclusions

In conclusion, this D12.5 deliverable report provides a detailed overview of the work undertaken by the CARBODIN Project during its first year by including a collection of the publishable information from the deliverables related to the demonstrators.

This report includes the project's progress in its three blocks and details the work done within WS2, WS5, WS6, WS8, WS10, and WS11.

Due to the delays in the Project, which went through an amendment process that reprogrammed for later D7.1 and D9.2, the progress on D6.2, D7.1, D9.2, and the rest of the publishable information will be made public in the second version of this report, D12.6 "Report on year 2 CARBODIN demonstrators".

9. References

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