The intermodal transport system ConnX, development and application

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2 Problem description

In public transport, individual transport lines are connected at junction points to form a transport network. When using cable cars in a transport network, the aim and challenge is to integrate the cable car into the existing transport network. This requires cable car stations to be built close to existing transport hubs, such as railway or metro stations in urban areas. The challenge here is to find suitable lines and suitable positions for the cable car station, especially in urban areas. As cable cars have system-related limitations, such as the size of the stations or the problem of curves in the line, the effort of integrating them into a transport network is high.

3 Intermodal transport

Intermodality refers to a transport route for which different means of transport are combined. When defining intermodal transport, a distinction is made between passenger transport and freight transport.

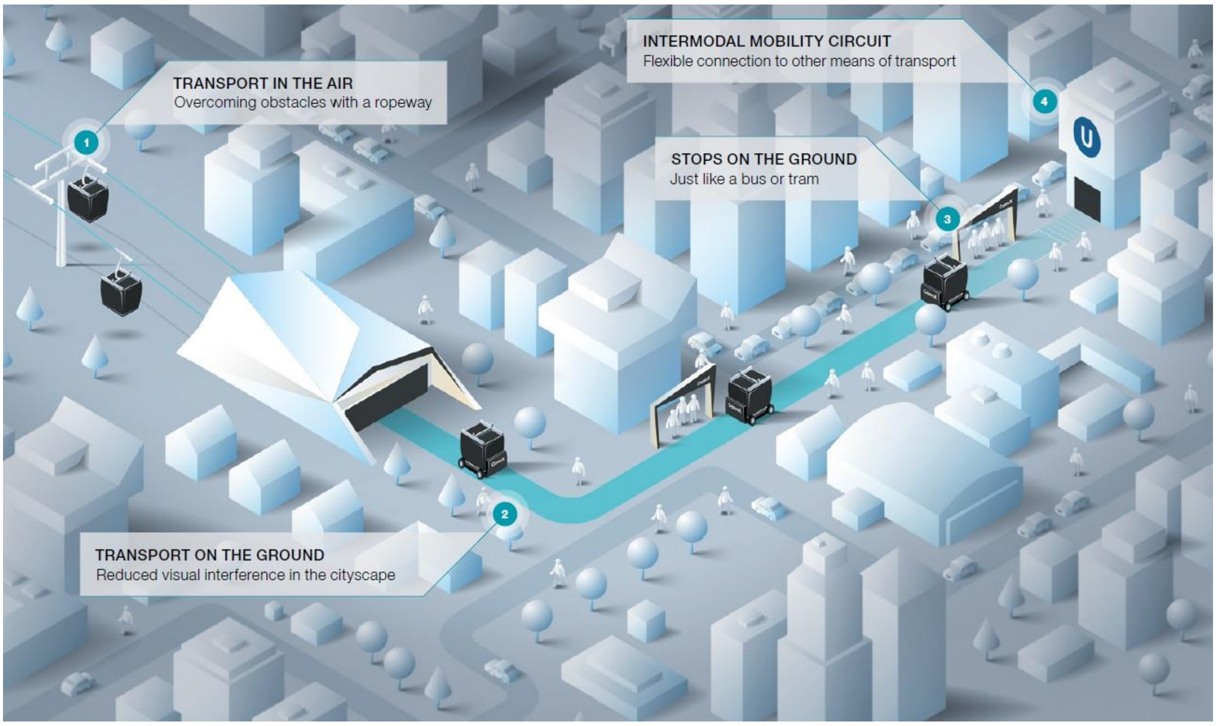

Figure 1: Intermodal transport system using the example of ConnX

In passenger transport, individual means of transport are linked together for a journey to be made. Passengers change from one means of transport to another for a journey. The change process between two means of transport should be as simple and convenient as possible to increase acceptance.

In freight transport, we speak of intermodal transport when standardized transport units, e.g. containers or semi-trailers, are used which are moved by different load carriers during transport.

4 The ConnX system

The "ConnX" transport system is an innovative, intermodal passenger and material transport system that combines a cable car system with self-driving vehicles. The cable car cabin is handed over to a self-driving vehicle at the transfer station, which continues its journey on its own driveway. ConnX offers a solution to the "last mile" problem of cable cars and simplifies the integration of a cable car into an existing transport network. In this context, "last mile" refers to the connection of a cable car station to another means of transport, such as a railway or metro station.

Thanks to the possibility of positioning the cable car station in a structurally favourable area and then using a self-driving vehicle to reach the "last mile" to the desired location without changing, the ConnX system contributes to the improvement of urban public transport and offers the possibility of integrating a cable car into an existing transport network.

The system enables the following:

- topographical or structural obstacles can be easily overcome with a cable car;
- easy bypass of infrastructural barriers on the ground - such as buildings or monuments;
- reliably maintain intermodal mobility cycles and avoid traffic jams;
- implement stops on the ground, similar to buses or trams;
- reduce visual impact in the cityscape;
- realize connections between cable car and terrestrial systems without passengers having to change vehicles;
- quick and cost-effective mobility solutions.

For example, a cable car can easily overcome large differences in altitude and have a station at the outskirts of a city. The cabins can then be transported onwards to a railway station on the ground using a self-driving vehicle.

From a technical point of view, the ConnX passenger transport system consists of a classic cable car section and a ground transport section with a number of automated vehicles. The different sections can be combined as required to form a complete system. The cable car cabins - with the passengers in the cabins - are transferred from the cable car section to the ground section and vice versa. The entire system is designed as a closed circuit in which the cabins circulate in both directions. However, the two sections can also be operated independently, or parts of the cabins can circulate in only one of the sections.

Passengers can enter and exit the cabins both at stops along the floor section and at classic cable car stations along the cable car section.

The entire system is operated and monitored via a central control system. The vehicles and the stops along the ground transport section are unmanned.

The overall system is an independent transport system that runs on a proprietary driveway that is demarcated from the outside in the floor section and cannot be used or crossed by other means of transport or pedestrians. This also eliminates the need for permanent monitoring of the driveway.

The overall system consists of several subsystems, which are described in more detail in the following paragraphs.

- Cable car section (6)
- Transfer station (1)
- Cable car vehicle (2)
- Self-driving vehicle (3)
- Driveway (4)
- Stop ground section (5)
- System control and monitoring

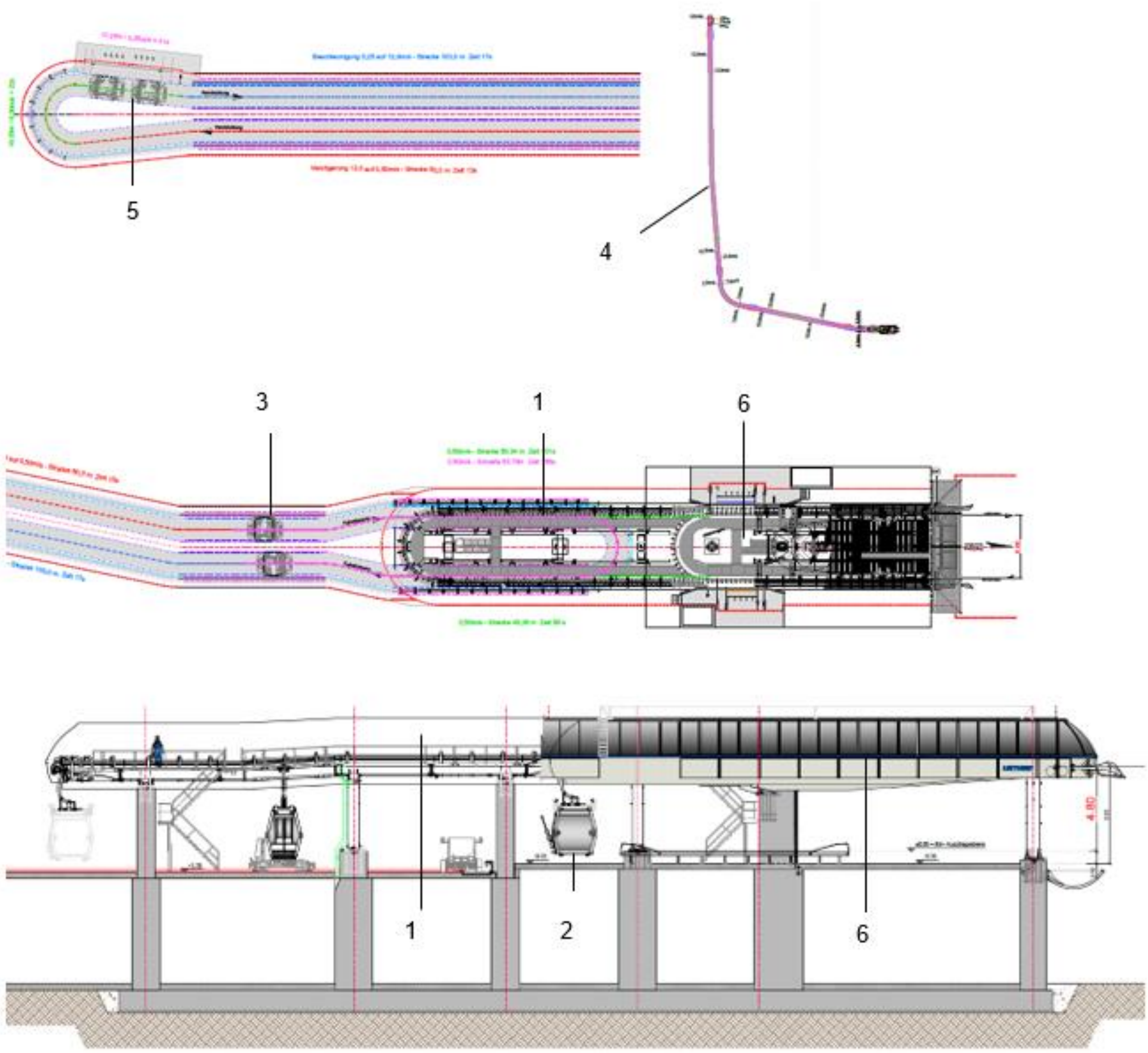

Figure 1: Subsystems of the ConnX system

4.1 *Cable car* section

The cable car section is a classic gondola lift. The transfer station is where the cabins are transferred from the cable car to the self-driving vehicles. The transfer station consists of a cable car section (6) and the actual transfer station (1).

The cable car section consists of a classic cable car station and is used to decelerate and accelerate the cabins and for passengers to load and unload. The drive or return station unit of the cable car section can be located in this section.

The other components of the cable car section, such as line structures, garaging facilities and stations, are standard components of cable car technology and do not require further description.

4.2 Transfer station

The transfer station is used to transfer the cabins from the cable car section to the ground section. The cabin doors remain closed and locked during the transfer.

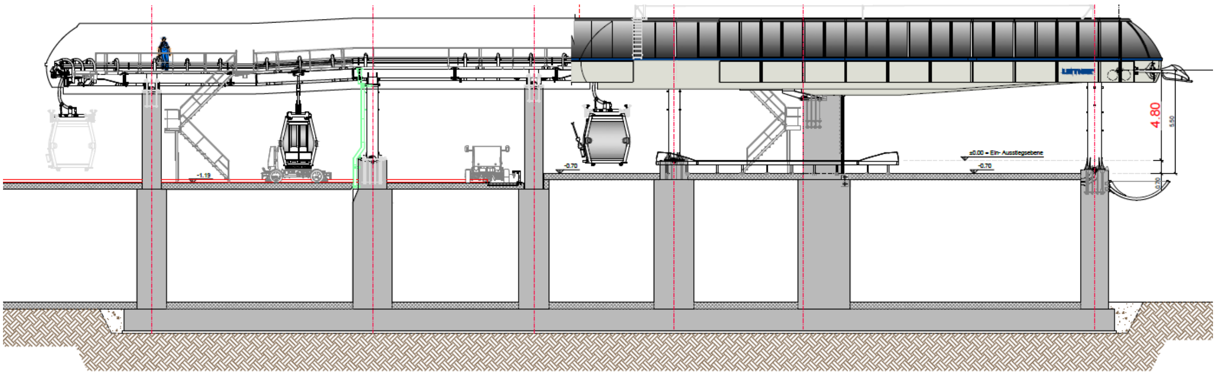

Figure 2: Transfer station

The transfer sequence is described in the following diagrams.

1. Approach of the vehicles

The cable car vehicles are moved along by a tyre conveyor driven by electric motors. The self-driving vehicle moves slowly in front of the cable car vehicle. The suspension is unlocked via a switch rail.

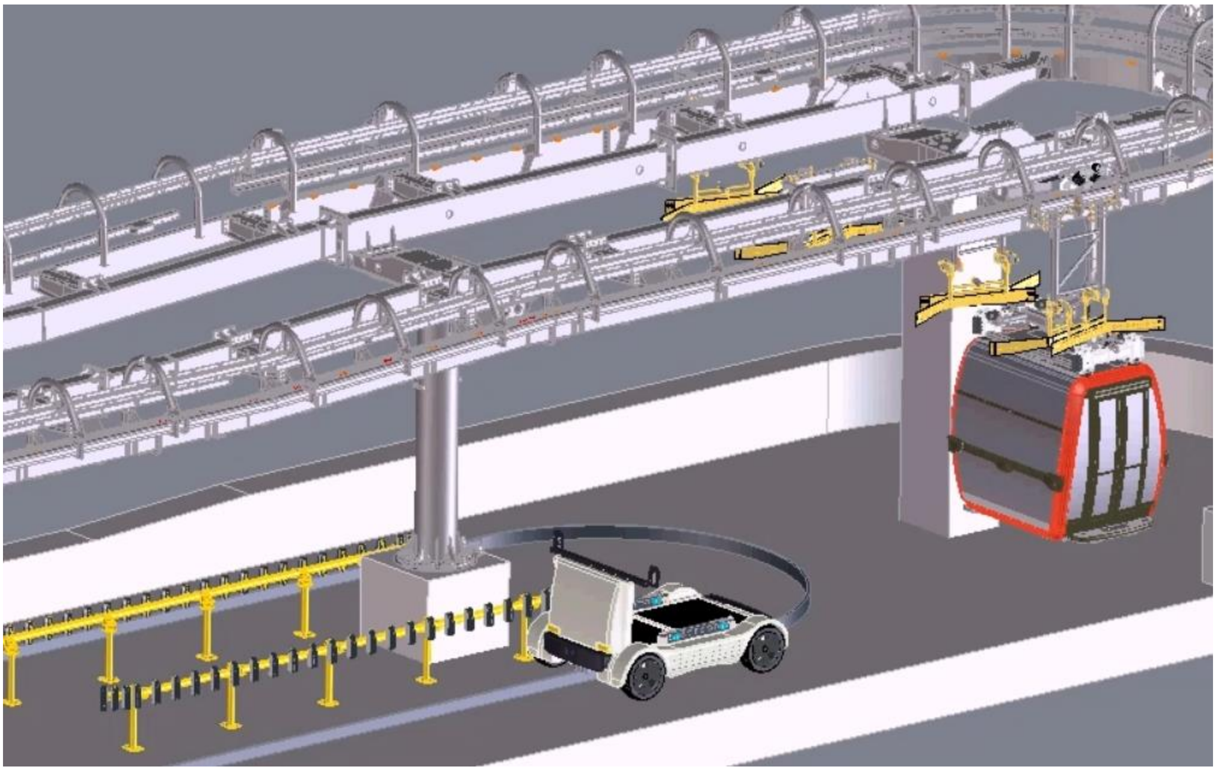

Figure 3: Approach of the vehicles

2. Synchronized running of the vehicles

The vehicles are approached in the station until the cable car cabin is above the self-driving vehicle, then the vehicles travel synchronously, and the cable car vehicle lowers over an inclined plane until the cabin rests on the self-driving vehicle.

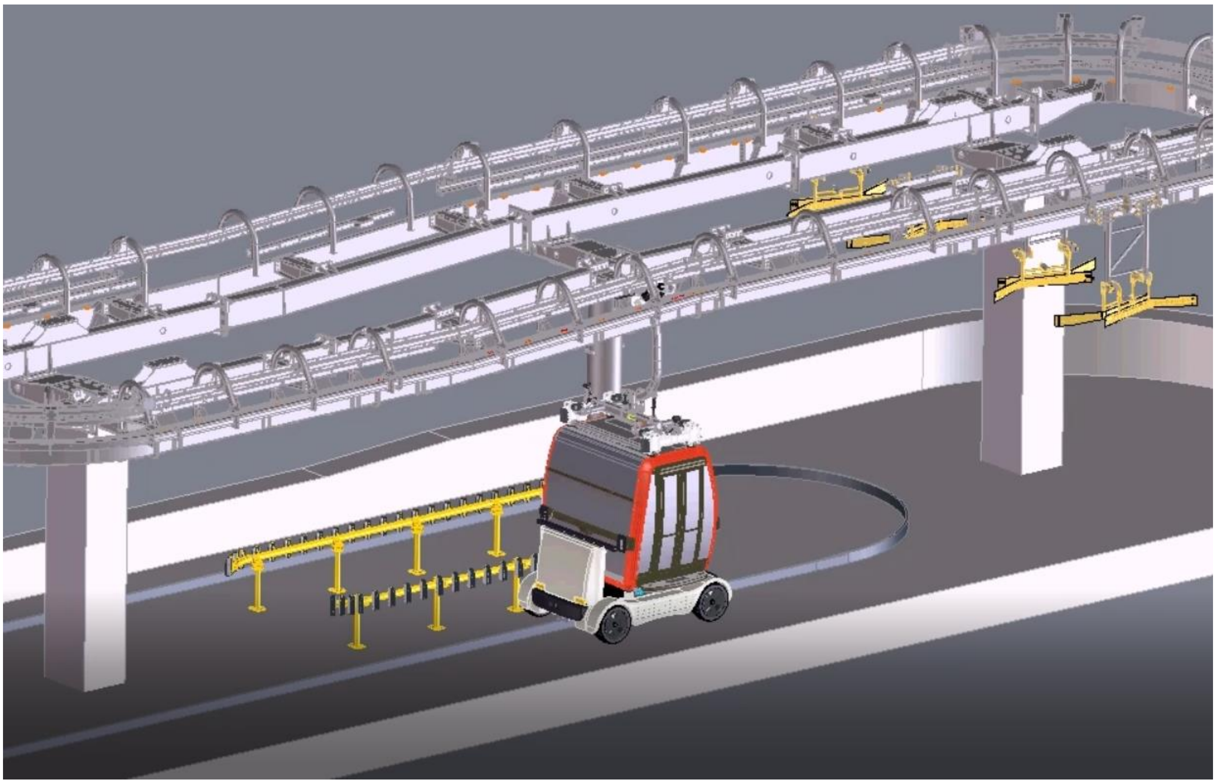

Figure 4: Synchronized running of the vehicles

3. Separation of cabin from suspension

After the cabin rests on the self-driving vehicle, the suspension with intermediate frame moves further downwards and thus detaches from the cabin. The suspension is then accelerated via the tyre conveyors and leaves the cab area. The cabin is locked to the self-driving vehicle.

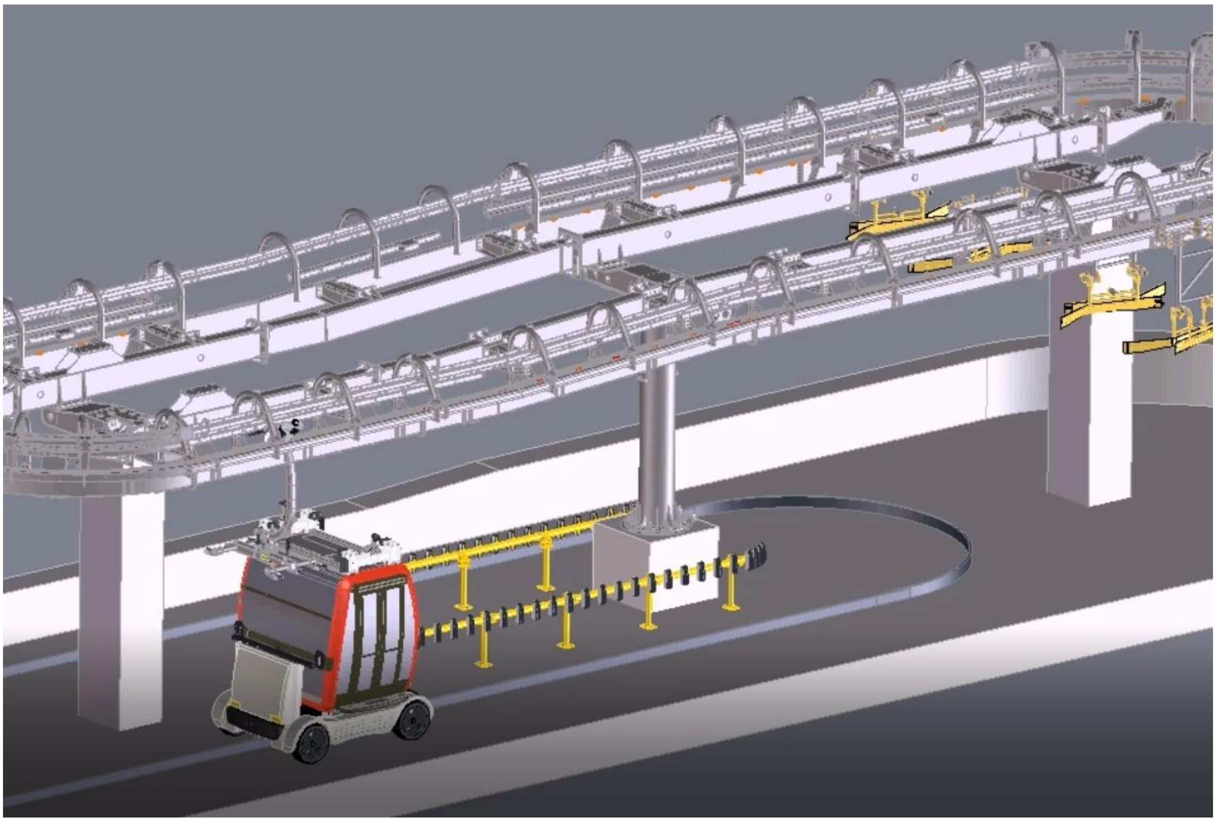

Figure 5: Separation of cabin from suspension

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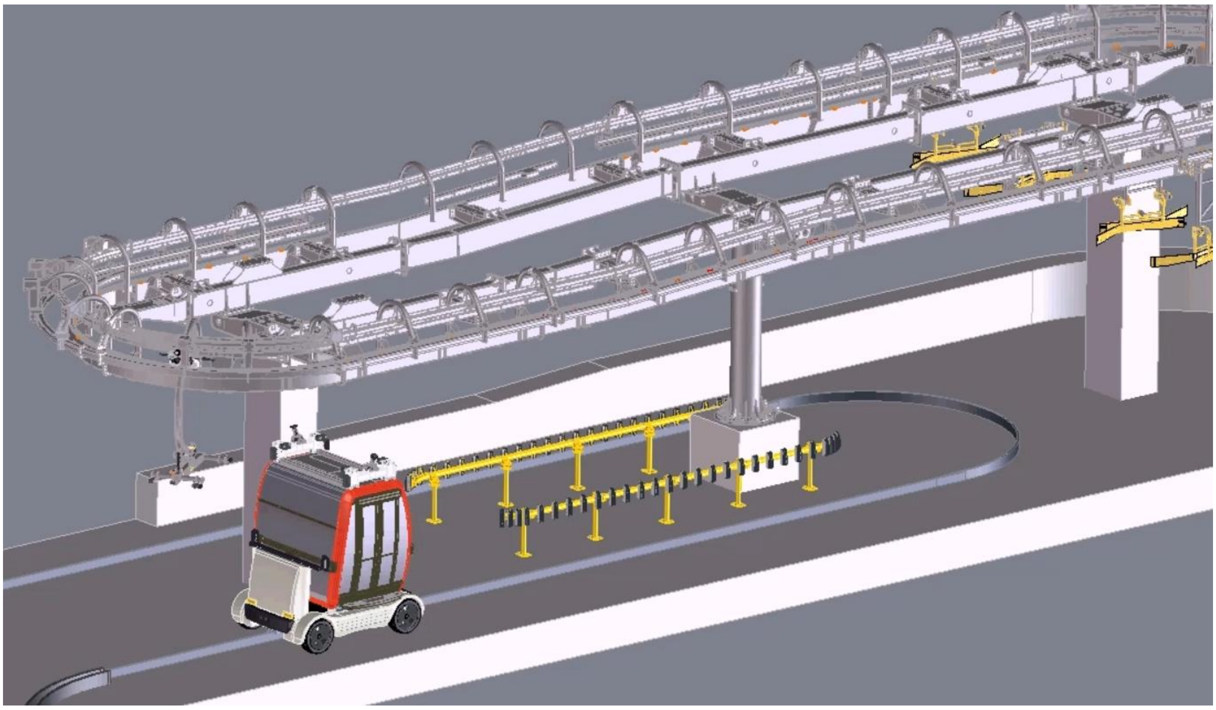

Figure 6: Suspension leaves cabin area

After the self-driving vehicle returns from the ground section, the cabin is transferred to the cable car section in the reverse process.

4.3 *Cable car* vehicle

The cable car vehicle consists of a cabin, an intermediate frame, a suspension system and a detachable cable clamp. The cableway vehicle is a subsystem in accordance with the EU 2016/424 Cableway Regulation.

The cable car cabin offers seats for all passengers, no seat belts are provided. No attendant is required. A bidirectional intercom system is provided in the cabin for communication with the system control centre.

The cabin doors are electrically operated. They are electrically locked in the cable car section. In the floor section, the doors can be unlocked and opened by the passengers for self-evacuation in an emergency.

In the transfer station, the cabin is separated from the intermediate frame and transferred to the self-driving vehicle.

4.4 Self-driving *vehicle*

The self-driving vehicle consists of an electrically powered driving module driven by in-wheel motors which drives on a proprietary track. The vehicle has pneumatic tyres and air suspension. In the initial development phase, the steering is done mechanically via a central guide rail on the ground, which controls the four steerable wheels. The guide rail is used to guide the vehicle on the driveway and in the station. In a later project phase, mechanical guidance is to be replaced by a sensor system and electric steering.

The braking system and the vehicle control system were designed in accordance with the requirements of the cable car standards. The implementation of a corresponding standard-compliant solution with the components available in the automotive sector is one of the major challenges in the project, as the safety concepts and service life requirements differ greatly in the two application areas.

Power is supplied by the vehicle's own battery, which is charged along the line or at the stations. The number of charging points depends on the length and topography of the line. The aim is to optimize the service life of the battery.

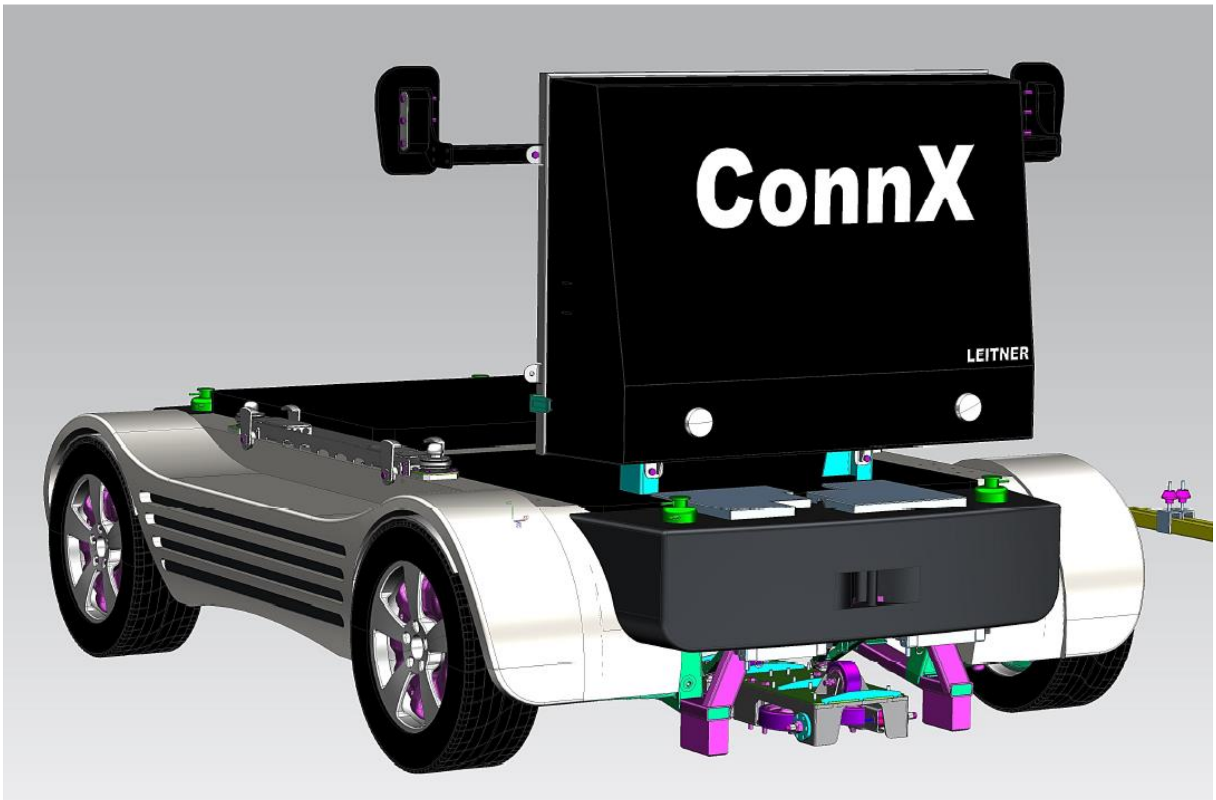

Figure 7: Self-driving vehicle

4.5 Ground track

The track consists of a driveway that is exclusively available to the ConnX transport system. The entire track is physically separated so that no pedestrians or animals of any substantial size can enter the driveway. The track can be realized as a ground track or as a bridge construction. It can also include tunnel sections. The gradient of the track is up to 10%, the curve radii depend on the traveling speed. The outward and return sections can also be separated and the track can thus be extended to form a ring.

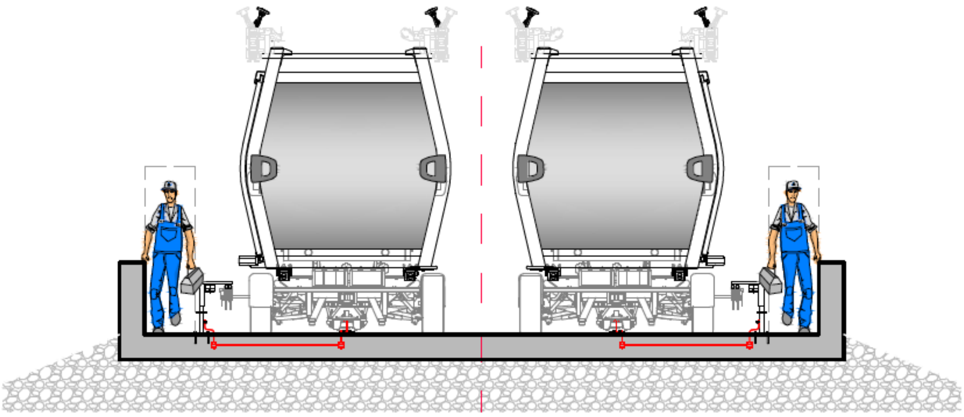

Figure 8: Track on the ground

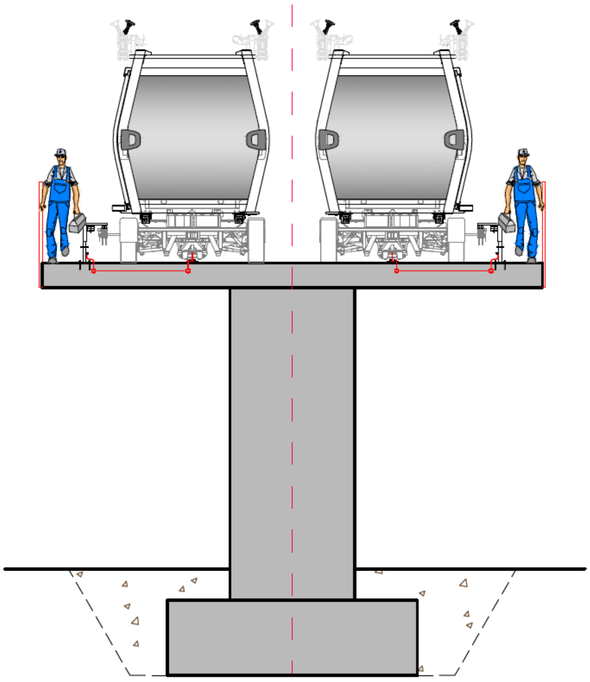

Figure 9: Elevated track

4.6 *Stop ground section*

The stop consists of a simple platform without platform doors; the stops do not require much space. Stops can be positioned along the track or in the reversal area. The vehicles move slowly through the stops with the doors open. The doors are opened and closed and the locking mechanism is checked after the doors have closed in the same way as in the cable car section.

If the transport capacity is low, the vehicles can also be brought to a standstill at the stops.

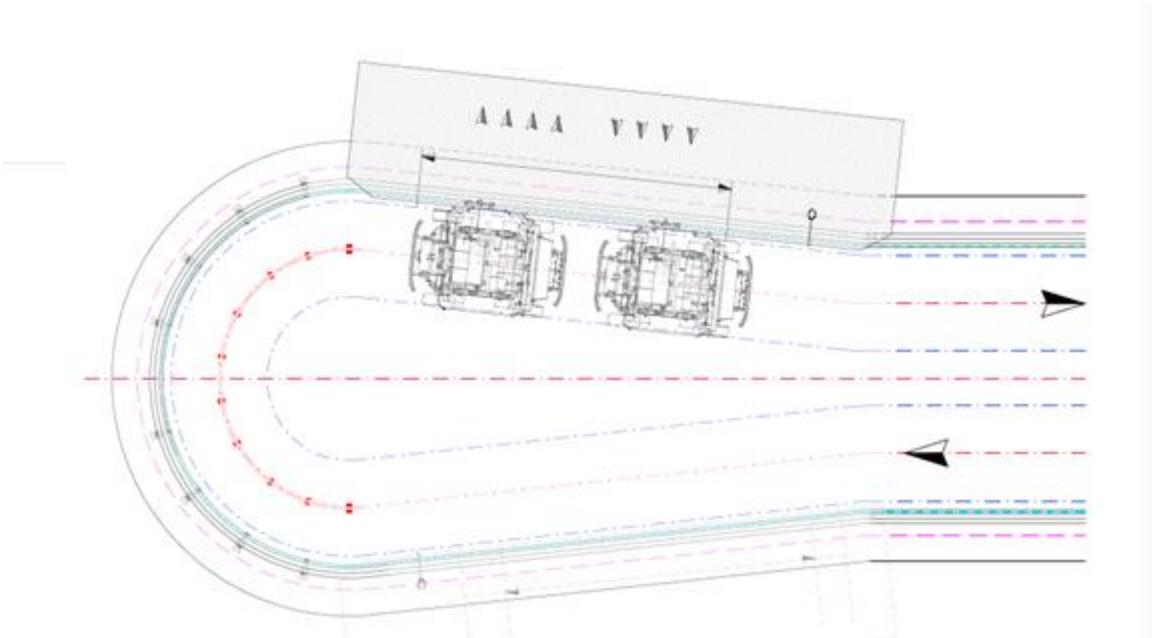

Figure 10: Station stop

4.7 Control and monitoring system

The entire ConnX system is operated and monitored via a centralized control system. The system control is preferably located in the transfer station. The system control includes the control of all stations, the line and the self-driving vehicles. Communication between the control system and the self-driving vehicles takes place via WIFI.

To control the vehicles on the line, the target position of each vehicle is calculated in a higher-level control computer and the current position is transmitted from the vehicles to the control computer. The required target speed of each vehicle is determined from this data and transmitted to the vehicle.

In stations where the position control must be very precise, the position of the vehicle and the grip is captured by additional sensors. The controller reads this sensor data and synchronizes the grip and the self-driving vehicle during the transfer process.

The central control system also monitors the system in the station and on the track. If the deviations between the pre-calculated target positions and the actual positions of the vehicles are outside a defined tolerance window, the system is slowed down or stopped.

The control system also provides a series of safety functions for the ConnX system.

5 Not technical challenges

When developing an innovative, intermodal transport system, there are many other challenges apart from the technical ones. As there are no adapted technical standards for such systems, it is necessary to take the necessary information from the technical regulations of various application areas to design a standardized and safe solution. The concepts and requirements in the cable car, machine and automotive worlds are often different or even contradictory and it is difficult to find a suitable solution for the system and to find suitable solutions for a consistent safety concept in the different standardization worlds.

At the start of the project, the intention was to get a self-driving vehicle from the market. However, it was soon realized that the promoted solutions were often just marketing or not suitable for the project. The technology for the self-driving vehicles was also nowhere near as advanced as expected. For example, fail-safe braking or steering systems are not yet available in the automotive sector or just in development. The technology and the safety concepts in the automotive sector are normally based on a human driver, that in case can take over the control.

6 Example Brixen railway station - Plose

In 2014 in Brixen/South Tyrol, a cable car was planned to connect the local mountain Plose with the city. The line was planned from Brixen railway station to the middle station in St. Andrä and on to the valley station of the Plose cable car. This project was rejected in a referendum by the local population. Main reasons of the rejection were the overflight of several residential areas, the line structures to be built in the urban area and the impact of stations to be built in the city.

The example shows an alternative using the ConnX system, with which it is possible to avoid the points of critique of the original project.