Deliverable D 5.1
Operational testing of first built-up Diesel- hybrid shunting prototype

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<th>Name</th>
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<tbody>
<tr>
<td>Joachim Reinhardt</td>
<td>DB Cargo</td>
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<td>Karl-Heinz Fölzer</td>
<td>AVL</td>
<td>Chapter 5</td>
</tr>
</tbody>
</table>
Figure 1 HELMS Locomotive Project ................................................................. 8
Figure 2 Principle of the HELMS Power Transmission .................................... 10
Figure 3 HELMS Principle of Power Split ......................................................... 11
Figure 4 Locomotive ready for the test bench .................................................... 15
Figure 5 Diagram of the test bench arrangement ................................................. 15
Figure 6 Comparison of Efficiency versus Speed .............................................. 17
Figure 7 Comparison of Efficiency versus Power .............................................. 18
Figure 8 Required measurement data for monitoring ........................................ 21
Figure 9 Required data channels for system monitoring - 1 ............................... 23
Figure 10 Required data channel for system monitoring - 2 ............................... 24
Figure 11 Required data channel for system monitoring - 3 ............................... 24
Figure 12 CRUISE M simulation model of the CLASS 294 hybrid locomotive .... 25
1. Executive Summary

This report embraces the tasks:

5.1: Analysis of state of the art propulsion systems for retrofitting

5.2: Operational validation of first built-up hybrid shunting prototype

The tasks T5.1 and T5.2 embrace the hybridisation of the legacy shunter DB Class 294, including analysis of the available technology, development, construction and testing under operational conditions. This project was named HELMS, the acronym for “Hybrid ELectro MEchanical Shunter”.

Hybridisation is a task to retrofit vehicles for the general requirements of efficient and environment friendly railway operation. The aims of hybridisation are:

- Increase efficiency
- Reduce emissions
- Reduce noise

By means of

- Energy storage devices on the vehicle
- Allow pure electric driving
- Allow to park the locomotive with active auxiliaries and without the necessity to keep the engine running.

The analysis of the available technology, under consideration of the features of the existing hydrodynamic driven Class 294, lead to the choice of an electro-mechanical system, which allows electric power transmission in conjunction with highly efficient mechanical power transmission. A high energy storage battery, using state of the art Lithium-Ion technology, is also installed. Development and construction of the Class 294 “HELMS” have been carried out successfully. Two prototype locomotives are completed, the first locomotive beginning 2018, the second one in early 2019.

After commissioning and pretesting, testing of the first locomotive under operational conditions has been carried out. In order to receive reproducible results, validation testing is carried out in a test rig which allows real simulation of train hauling and shunting. By this testing, validation of the desired functions as well as of the results with respect to energy saving has been proven. As soon as these tests have been completed, the locomotive will take test runs on the track for further
measurements, e.g. for homologation purposes, and will later go into commercial service. For the future it is planned to install this system on the majority of the Class 294 fleet within DB – these are approx. 300 units.

2. Abbreviations and acronyms

<table>
<thead>
<tr>
<th>Abbreviation / Acronyms</th>
<th>Description</th>
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<tr>
<td>DB</td>
<td>German Railways (Deutsche Bahn)</td>
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<tr>
<td>HELMS</td>
<td>Hybrid electro-mechanical Shunter</td>
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<tr>
<td>DC</td>
<td>Direct current</td>
</tr>
<tr>
<td>AC</td>
<td>Alternating current</td>
</tr>
<tr>
<td>EMS</td>
<td>Energy Management System</td>
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3. Background

The present document constitutes the Deliverable 5.1 “Operational testing of first built-up Diesel-hybrid shunting prototype” in the framework of the FR8HUB WP5 – Hybridisation of legacy shunters, task 5.1 and 5.2 of FR8HUB within IP 5 TD5.4. The tasks referred to are named as follows:

- 5.1: Analysis of state of the art propulsion systems for retrofitting
- 5.2: Operational validation of first built-up hybrid shunting prototype

The two tasks have been realized in the project within FR8HUB WP5 which comprises the development, design, constructing and testing of the hybridization of legacy shunters Class 294 of DB Cargo. As these locomotives are built for long lifetime and are still in a reasonable condition, expecting a further lifetime of at least 16 years, they have been found worth to develop and install a system which

- Increases efficiency – fuel saving of about 20% is predicted
- Decreases emissions
- Allows emission free electric driving, sourced from a storage battery
- Allows to park the locomotive with active auxiliaries and without the necessity to keep the engine running.

It is planned by DB to install this system on the entire fleet of about 300 Class 294 locomotives if the system will prove functionality as well as the expected reduction of fuel consumption.
4. Objective/Aim

4.1. The Refurbishment Concept HELMS

The Class 294 is a Diesel locomotive with hydrodynamic transmission (Voith transmission), designed in the sixties and produced over many years in a high number of units. The main purpose is shunting as well as hauling freight train over short or medium distances.

The 1000 kW locomotive experienced several refurbishments, e.g. installation of a remote control as well as installing of new diesel engines. However, the hydrodynamic transmission limits the possibility of modernization with respect to reduction of energy consumption, noise and emissions.

Considering those facts, change from hydrodynamic to electric power transmission, which offers several possibilities for hybridization, has deeply been studied. Reuse of as many components from the existing locomotive as possible, in particular the engine system and the bogies, was also an important goal to get an economical solution for the modification.

The solution finally selected is an electric three-phase power conversion with a Li-Ion storage battery. Considering the special conditions of the existing locomotive, a special gearbox was planned, which allows split of the energy transmission in an electrical and a mechanical line, which are automatically balanced to receive best possible efficiency. Using this solution, engine system as well as the bogies could be used without modifications.
Within this project the following tasks have been carried out:

- Analysis of the state of the art propulsion system for hybrid vehicles
- Creating the basic ideas
- Specification of the systems and components
- Carrying out the basic development
- Carrying out the detailed design for production
- Required preparation for material sourcing and production
- Construction and refurbishment of two prototype locomotives
- Validation of the system functions and first testing

4.2. Technology of the HELMS Locomotive

This chapter describes function and components of the HELMS Locomotive as well as the differences to the legacy Class 294.

4.2.1. Existing Locomotive Class 294

The principle power conversion of the Class 294 is hydrodynamic. The function is as follows:

- Power source is an eight cylinder Diesel engine Type MTU 8V 4000 R41.
- The power is transmitted by means of a cardan shaft to the Gearbox type Voith 206rs.
- The Voith gearbox contains hydrodynamic torque converters which adapt torque and rotation speed of the diesel engine to the desired speed and tractive effort of the locomotive.
- The power and torque output of the Voith gearbox is transmitted by cardan shafts and axle-wise gearboxes to the wheelsets.

Influencing of tractive effort and locomotive speed is mainly by engine speed. The operator controls only engine speed to receive the desired traction results. As only engine speed controls the tractive effort, the engine cannot be run in the most fuel economic areas of the engine characteristic. For example, receiving full tractive effort at locomotive start, that means starting with a heavy train, required nearly maximal engine speed, while the required power is low. In this point of the engine characteristic, the specific fuel consumption is high. Furthermore, storing and use of braking energy is not really possible.

In spite of those disadvantages, hydrodynamic power conversion was chosen over long years, as this system is simple, reliable and does not need special control systems, which have not been available in this time anyhow.
However, today’s requirements for fuel economy, environment protection and hybridization cannot be realized with hydrodynamic power transmission. Thus, alternative ways had to be developed to modernize the legacy shunter Class 294.

4.2.2. The Function of the HELMS Locomotive

The principle of the HELMS Idea is splitting the Energy from the diesel engine in a mechanical line and an electrical line, see picture below:

![Figure 2 Principle of the HELMS Power Transmission](image)

The function is as follows:

- The diesel engine drives the generator, which generates three phase AC current
- An active rectifier, part of the traction converter system, rectifies the AC current to DC current, source into the DC link. The rectifier is able to control the voltage in the DC link.
- The traction motor converter, also part of the traction converter system, powers the two traction motors.
- The traction battery is directly connected to the DC link. Loading/unloading is simply done by controlling the DC Link voltage.
- Electrical braking by remuneration of the energy from the traction motors, now working as generators, DC link and usable to charge the traction battery.

The specially developed HELMS gearbox contains, besides several connecting gear trains, two functional components essential for the HELMS principle:

- A dividing gear, characterized by a planetary gear drive, which distributes the torque generated by the diesel engine, into torque to the generator and torque to the mechanical line. This distribution is fully automatically, depending from the counter torque of the generator.
- A summation gear, which collects the torques respectively the power coming from both, the electrical line and the mechanical line.

The following picture shows the principle of the energy split

![Figure 3 HELMS Principle of Power Split](image)

Contrary to the existing Class 294, traction control at the HELMS locomotive is power control which is triggered by the operator’s master controller. The traction control system requests power from the diesel engine and/or the traction battery as well as controlling the generator and the traction converter.
An Energy Management System (EMS) allows energy efficient operation, e.g. by different patterns for use of the traction battery or controlling of auxiliary systems. This system is overlaid to the traction control system. The locomotive operator has several choices, depending on the kind of service.

The HELMS principle offers various advantages:

- Possibility to integrate the system into legacy shunters like Class 294 in an economic way, reusing engine system and bogies
- Low fuel consumption by using highly efficient mechanical transmission for an important part of the traction energy
- Offering a hybrid system with energy storage and reuse of braking energy
- Possibility to operate the locomotive emission free powered by the traction battery

4.3. Progress of the Project

At the end of February 2019, the project progress is as follows:

- 2 Locomotives are fully assembled
  - Locomotive #1:
    o Is completely commissioned
    o Testing on the test bench started in early 2018
    o First test showed positive results
    o Testing sequence was interrupted by several technical issues
    o Several improvements have been introduced in the meantime
    o Restart in February 2019
    o Locomotive foreseen for track testing
  - Locomotive #2:
    o Commissioning in Progress
    o Locomotive foreseen for homologation test runs
- Existing Class 294:
  o Measurements necessary for comparison with HELMS have been carried out on the test bench
5. Operational Testing

5.1. Purpose of testing

Testing of the locomotives is and will be done with respect to the following aims:

a. Proof of the functionality of the locomotive, including but not limited to:
   - Function of all control circuits
   - Performance: proof of the specified speed/tractive effort diagram
   - Answer to sudden load changes
   - Stability of performance, e.g. temperature rise of cooling systems, permanent full load situations

b. Measurement of economic and environmental data
   - Fuel consumption under various load and track scenarios
   - Noise
   - Emissions

c. Getting data for optimization, mainly with respect to further reduction of fuel consumption
   - Adjusting of control sequences
   - Optimized driving behaviour
   - Best economical use of diesel engine

5.2. Execution of Testing

Operational testing is understood as testing of operational driving situations. As most important result those tests shall show reduction of fuel consumption with the HELMS locomotive, in comparison with the original Class 294 characterized by hydrodynamic power transmission. An important feature of those testing is to ensure identical conditions for both locomotives. It is well known, that this requirement can hardly be fulfilled during field testing, as several conditions, such as weather, operator’s behaviour or track availability, can hardly be kept identical over several test runs. For the HELMS locomotive two ways are established and planned:

A: Testing on a Test Bench

A test bench has been installed, which allows testing under power in a wide range of the tractive effort/speed diagram. This allows, in addition to the required functional testing of the locomotive systems, simulating of test runs under operational load conditions. Using this test bench for operational test runs, identical conditions for both vehicles can be ensured. Those tests, called
integration tests, are already in progress. For comparison, a “normal” Class 294 has also been measured on the same test bench under similar conditions.

**B: Track testing**

Track testing is foreseen in several steps:

1. **Test runs for measurements, in particular for homologation purposes**
   - Test runs with non-commercial trains for the purposes
   - Education of operating staff
   - Functional testing under real service conditions
2. **Measurements during train runs**
3. **Revenue test runs with commercial trains**
   - Final proof of functionality under revenue service conditions
   - Final proof of economic advantages in comparison with the original Class 294
   - Service with commercial trains is only allowed after homologation by the authority EBA (Federal German Railway Authority), i.e. those tests cannot be performed earlier than end of 2019.

**5.3. Structure of the Test Bench**

The test bench shall allow to run the locomotive as far as feasible like in the real operation. For that purpose, an arrangement as described in the following has been constructed.

The complete locomotive is placed on special bogies, which contain, instead of the axle drives, an electric motor, which is driven by the cardan shafts from the gearbox. These cardan shafts are driving the axles of the locomotive.

The electric motor is working as an electric brake. The energy produced by this motor during “driving” is converted into heat in special resistors, which are installed outside the building. Those resistor banks are existing at the Cottbus workshop of DB and normally used to test diesel-electric locomotives after refurbishment or reparation. These motors are DC – motors, normally used as traction motors in diesel-electric locomotives Class 233 of DB. The required excitation is provided by a locomotive of this class, standing outside of the building.

This arrangement allows to run the locomotive under load, mutually controlled by the locomotive operator and the control mechanism of the resistors and the locomotive providing the excitation for the brake motors installed in the test bogies – as seen in Figure 4 and Figure 5.
To keep costs and timeline within reasonable limits, the resistor arrangements as well as the brake motors are taken from existing equipment, only slightly modified for the purpose of the integration test. By that, some of those limits are however not essential for the intended purposes.

In addition to the measures regarding the energy flow, a huge amount of measurement equipment is installed at the test locomotive to receive the necessary data, such as:

- Power, rotation speeds and torques in the energy flow
- Temperatures of equipment of the electric equipment as well as the engine circuits
- Torsional vibrations in cardan shafts, gear box and electric machines
- Status of control signals, digital as well as analogue
- Software data
- Fuel consumption
- Operational data of the test bench

The measured data are transmitted to the test bench control centre. Important data can be continually monitored by several screens. All data are stored and can then be evaluated and interpreted to allow deeper analysis and, if required, to develop improvements or optimising the system.

5.4. Performed Tests with the original Locomotive Class 294

A Class 294 taken out of service was installed on the test bench with the main purpose to measure fuel consumption under the same conditions and at the same operation patterns as foreseen for the HELMS locomotive.

The locomotive was placed on the test bogies taken from the HELMS locomotive. Cardan shafts have been adapted in length and the measurement equipment as created for the HELMS locomotive was installed as far as feasible for the diesel hydraulic driven Class 294.

Essential test results regarding efficiency are shown in Figure 6 and 7. Important “Lessons Learned” is that the diesel engine as well as the hydraulic power transmission gearbox (Voith gearbox) are showing remarkable differences in efficiency compared with the theoretical values as taken from the datasheets. Those differences are caused by production tolerances as well as by maintenance stages of these legacy locomotives, several decades old. It is to be expected, that such differences can influence comparability of measurement result. This fact must be taken into account very carefully for final examination of measurement results.

5.5. Performed Tests with the HELMS Locomotive

At first, inauguration tests have been performed to ensure functionality of test bench, measurement equipment and locomotive. The tests had shown that several corrections and improvements had to be carried out. The tests had to be stopped two times for required reparations on the gearbox, once caused by a handling failure, a second time due to a problem inside the gearbox. The break time has been used to carry out other improvements in the electrical system, the mechanical power line and the electrical system.
It is not part of this report to explain technical details which made some rework necessary. However, the fact that such bugs could be discovered and improvements and correction could be performed in an early stage shows clearly, that new developed systems for railway vehicles require deep testing of the functionality before starting revenue service on the track. Testing on a test bench allows to concentrate on the technical issues without necessity to care for track requirements or allowances.

As fuel saving is the most important topic for the development, measurements of fuel consumption have been in the focus of the measurement.

First results are shown in the Figure 6 and Figure 7.

![Figure 6 Comparison of Efficiency versus Speed](image)
The improvement of efficiency as illustrated in the figures 6 and 7 cannot be converted directly into fuel saving, as other positive effects are not considered in this initial testing:

- Fuel saving effects by the use of the traction battery, in particular for short runs or parking of the locomotive ready to run
- Low speed/low power operation, where the new system has important advantages, could not be realised on the test bench for the HELMS locomotive

5.6. Testing on Track

A comprehensive test session on track is planned. The test will be carried out using train rides typical for the Class 294 locomotives, in particular shunting service with heavy trains and train rides over medium distances.

Similar measurement runs have been carried out with an original Class 294 locomotive, so that a good comparison is possible.
For the test runs, the locomotive is equipped with a big amount measurement equipment to collect important operational and technical data, in particular fuel consumption. For the time being the following test runs with the HELMS Locomotive are planned:

1. Tracks area of Senftenberg/Cottbus
   - Initial test runs for ensuring function of locomotive an measurement equipment and carrying out necessary adjustments
   - Several train runs with trains 200t to 1400t

2. Track Schwandorf – Furth im Wald (Bavaria)
   - Track Schwandorf to Furth im Wald with 300t train
   - Track Furth im Wald to Schwandorf with 1250t train
   - Service to an industrial plant with about 650t train, shunting inside the plant

3. Track Schwandorf to Regensburg (Bavaria)
   - Track Schwandorf to Regensburg with 1150t train and 700t train
   - Track Rgensburg to Schwandorf with 850t train and 500t train

4. Area Marktredwitz - Hof – Reuth (Bavaria)
   - Several train runs with heavy train in hilly track, characterized by long inclined lines.
   - Shunting service in the stations Hof, Marktredwitz and Reuth
   - Total duration about 8 hours, about 170 km running distance

5. Track Hagen – Ennepetal (Area Rhein-Ruhr)
   - Track Hagen to Ennepetal with 770t train
   - Service on several industrial plants with trains up to 600t
   - Track Ennepetal to Hagen with different train weight

6. Shunting service in station Oberhausen (Area Rhein-Ruhr)
   - Short track service with different train loads for about 4hours
   - Shunting service on shunting hill with different trains up to 1150t, duration about 2,5 hours

7. Tracks in Cologne area
   - Track run with train 220t
   - Shunting service
   - Track run with train 1100t

8. Service at shunting yard Maschen (Area of Hamburg)
   - Track runs with trains up to 340t with high and low speed
   - Different shunting service with trains up to 585 t
   - Duration about 8 hours, running distanced about 75km

9. Shunting service Hamburg terminal
Short runs to customer plants with trains about 950t
Several runs at the shunting hill with different train weights

10. Tracks area of Senftenberg/Cottbus
Several train runs with trains 200t to 1400t
Several test runs for ensuring function and carrying out adjustments

However, the tests as intended are depending from the allowance of the authorities. Commercial service will probably not be allowed prior to the final homologation of the locomotives. Because of this fact, a backup solution is in planning.

As backup solution is foreseen to carry out the test runs similar to the planning as explained above, however simulating the train loads by an electric locomotive, providing the train load by electric braking. In this case, the test train will consist of:

- 1 HELMS locomotive
- 1 original Class 294 locomotive
- 1 electric locomotive

This test train configuration allows, measuring the performance of the HELMS locomotive as well as the original Class 294 locomotive under nearly identical conditions.

6. Optimisation Activities by AVL

Regarding AVL’s contribution in the WP5 measurement data are needed for 2 reasons. The first one is to set up a system simulation model which reflects the baseline configuration of the hybrid shunting locomotive Class 294 from DB. The second one is to develop a concept for an extended energy system monitoring.

6.1. Installation of the condition monitoring system EPOS

AVL’s own monitoring system called EPOS is based on an indication of a cylinder pressure trace. Therefore, by measuring and analysing the engine cylinder pressure the condition of the internal combustion engine, the engine efficiency and other performance data can be derived. In addition to that emission measurement and turbocharger measurement can be added on the system.

For the objective in WP5 the data would have been used for analysing the operating point and its current operating efficiency. Furthermore, it was planned to extend the features of the monitoring
system by Non-engine data as e.g. data from energy storage system (batteries), gearboxes, motors and generators and all other devices within the drivetrain chain. With that kind of data an overall system energy balance could be performed and visualized. In a next step the actual data will be taken to derive upcoming operating strategies.

Unfortunately, it was not possible to install the system on the shunter engine. Therefore, a cooperation with the engine manufacturer would have been required what at the end could not be established in the project. Without support from the engine builder machining the cylinder head is very risky respectively not recommendable. A work around had to be found to receive data from the Diesel engine.

6.2. On-board measurement data from the locomotive system

Stepwise approach:

- Data measurement
- Data visualization
- Data operation
- Operating strategies

Figure 8 Required measurement data for monitoring
Since the condition monitoring system was not installed on the Diesel engine a work around had to be found. By having operating maps from the engine (BSFC data in dependency from engine speed and engine power) the actual fuel consumption can be defined. Therefore, it is required to digitalize these maps which are coming from the shop test. After digitalization of the maps BSFC as function of engine speed and engine power can be calculated. An overview of all data required for a system monitoring is shown in Figure 8.

So finally, the efficiency of the operating point in which the Diesel engine is currently running can be observed, visualized and at the end operating strategies can be derived e.g. increase engine load plus battery charging.

Mechanical consumers: power input

For energy balance point of view, it is important to detect the losses which are reducing the mechanical output of the engine itself because they have in impact on the positioning of the operating point in the map. Without knowing the losses, the fuel consumption of engine would be assigned slightly wrong.

Battery system: state of charge, cell temperatures, voltage, charging and discharging current

Knowing the state of charge of the energy storage system in conjunction with the engine operating efficiency is the base for an optimized energy efficient system operation. So as an example, if the main engine is operating at low load where typically the specific fuel consumption is worse, and the battery state of charge is also low it must be questioned if it would make sense to operate the main engine in higher load points and charge the battery with the additional available energy.

In addition to that the energy flow in and out of the ESS should be observed. That means voltage and current data of the electric components, not only the battery should be measured. Main reason is to identify the system condition from energy point of view. But also, for predictive reasons the health of the ESS should be recorded.

Transmission system: actual gear ratios, gearbox losses, rotational speeds

From the complete transmission system, the losses are from interest, not only for detection of the actual status, also for a potential future condition monitoring system the health of the hardware is of importance to avoid unplanned stand still or damage.
General data: ambient conditions and compartment conditions (pressure, temperature, humidity), locomotive velocity, train load, track profile (inclination, GPS data)

The ambient conditions and the conditions in the engine room have impact on the mass flows into the system and on the thermal conditions with respective to component cooling. The information regarding the boundary conditions of the train are important for further system operation strategy, so the knowledge about upcoming track profile, target velocity and required traction effort are helpful for calculating the efficiency optimized actual operation.

A detailed compilation of the measured parameters including typical measurement hardware is given in Figure 9, Figure 10 Fel! Hittar inte referenskälla. and Figure 11. During the preparation phase it turned out that most of the required data are already considered to be measured anyhow, therefore an additional measurement hardware on the locomotive seems not be required.

<table>
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<tr>
<th>Component</th>
<th>Parameter</th>
<th>Comment</th>
<th>Required Hardware</th>
<th>Example Type</th>
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<td>Pressure</td>
<td>Pressure sensor</td>
<td>VoltaL Ptb 210-220 or Ptb 330</td>
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<td></td>
<td>Temperature</td>
<td>Pt 100 for up to 300°C</td>
<td>Temperature sensor</td>
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<tr>
<td></td>
<td>Humidity</td>
<td>Humidity sensor</td>
<td>VoltaL HMP 233 or 210</td>
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<td>Engine room condition</td>
<td>Pressure</td>
<td>Pressure sensor</td>
<td>VoltaL Ptb 210 / Ptb 220 Class A</td>
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<td></td>
<td>Temperature</td>
<td>Temperature sensor</td>
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<td></td>
<td>Traction effort</td>
<td>Currently only visualized in control room, no recording existing calculation with function (load, inclination, velocity)</td>
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<td>Manual information regarding incidents failures</td>
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<td>Distance</td>
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Figure 9 Required data channels for system monitoring - 1
Another main task within WP5 is the simulation of the hybrid locomotive operation. This is done with the AVL code CRUISE M. CRUISE M – from now on abbreviated as CM – is a real-time system simulation platform for simulating the complete energy flows in an application. It can be additionally extended by calculation of the cooling circuit or the lubrication circuit, but this was not used in the recent work package.
The model reflects all the components in the drivetrain: The Diesel engine, the transmission, the gearboxes, the generator, the battery system, the traction motors, and the wheel sets. A sketch of the simulation model is given in Figure 12.

The elements connected with yellow lines are representing the electrical circuit including the main components battery, generator and the traction motors - two of them compiled in one element. The elements connected with green lines are representing the mechanical circuit including the main components internal combustion engine – in our case a V12 high speed Diesel engine – the planetary gear and the wheel sets with the brakes.

![Figure 12 CRUISE M simulation model of the CLASS 294 hybrid locomotive](image-url)
For a high result prediction quality on the one hand the base information of all the implemented components and their arrangement are important. That means that either detailed specification is required to set up a model on component level e.g. for the Diesel engine all the intake and exhaust design geometry, the combustion characteristics, the gas exchange parts such as valve lift curves or port flow coefficients. Doing so the simulation can calculate the engine fuel consumption itself. Or the component is modelled as a fixed performance map where the relevant fuel consumption is depending on engine speed and engine load. Such data can be obtained via a shop test of the engine supplier.

Very similar other components of the drive train are modelled, the final performance e.g. efficiencies could be calculated within the simulation or it could be mapped.

In addition to the baseline data for model set up a good set of measurement data is required to calibrate the model as far as possible to the real-life operation. For that reason, it is mostly efficient to have data from typical operation in the field. This would give the benefit in having the demands to a shunting locomotive in conjunction with the resulting performance of the existing system. A recalculation of the existing status would give a high-quality baseline for optimization work and analyzation of the running hardware.

For the shunter 5 operating modes are considered:

- Mode 1 - Pure electric drive: electric energy from the battery to the traction motors & summary gear to the wheel sets
- Mode 2 - Pure Diesel propulsion: mechanical drive from the Diesel engine over the planetary gear to the summary gear and the wheel sets
- Mode 3 - Battery charging: The Diesel engine drives over the planetary gear the generator which produces the electric energy for loading the battery
- Mode 4 - Battery charging and mechanical propulsion: this is a combination of mode 2 and mode 3
- Mode 5 – Recuperation: this mode can be done on demand, braking energy will be used to charge the battery

All the 5 modes can be simulated and as a first result of the measurement simulation the overall Diesel fuel consumption of a typical shunting work will be obtained. In the next phase optimization loops are considered so e.g. the impact of an ESS with higher capacity on the fuel efficiency will be simulated.

Answers of following questions can be given:
- What is the optimum minimum battery capacity in terms of fuel saving
- What is the advantage in terms of acceleration of the train
- What would be the required current for charging the battery in recuperation mode
- What benefit could be gained by replacing the existing Diesel engine by another type with lower power output
- What impact on system efficiency can be achieved by changing boundary conditions such as the operating range of the battery

These simulations are planned to be carried out in the subtasks 5.4 and 5.6.

7. Conclusions

The conclusions reached at this stage of the Project and highlighted in this report are:

- The development, detail design and construction of the hybrid locomotive HELMS, a refurbishment of the legacy locomotives Class 294, has successfully been completed
- Different technical issues have delayed the project. However, all upcoming issues have been solved successfully, the technical project aim is not in danger.
- The HELMS locomotive is currently under testing on the test bench, where comprehensive measurements are under way, ensuring functionality and indicating fuel savings. Tests at the test bench can be carried out under operational conditions
- Operational track testing is under planning. Depending on the allowance of the authorities, the test are done either with commercial freight trains or – as a backup – by simulation of train loads by means of an electric locomotive.