THE FUTURE OF EUROPEAN DIESEL TRACTION

FLEET SCENARIOS, EMISSION REDUCTION & ENERGY EFFICIENCY POTENTIALS

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Energy Efficiency, the best fuel to move our trains!
PRESENTATION OUTLINE

• Introduction
• Sustainability Study
• Sustainability Impact Assessment & EE
• Conclusions
GENERAL OBJECTIVES

CleanERD

• Demonstrate the feasibility and reliability of railway rolling stock powered with stage IIIB diesel engines, scenarios beyond IIIB

SP Sustainability & Integration

• Reliable rail diesel vehicle fleet and emissions scenarios
• Cost/ Benefit Analysis and Sustainability Impact Assessment
• Recommendations on future emission reduction approaches
PROJECT STRUCTURE

SP0 Management

SP1 System Requirements

Management

SP2 Railcar

SP3 Heavy Haul

SP4 Light Weight

Demonstration projects

SP5 Sustainability and Integration

SP6 Emerging Technologies

SP7 Hybrid Solutions

SP8 Dissemination

Studies / Analyses

UIC ENERGY EFFICIENCY DAYS 2014
CURRENT STATUS: NOx & PM EMISSIONS FROM TRANSPORT

Rail’s diesel share of total NOx emissions is 2.5%, reduction by 35% (1990-2008)

Rail’s diesel share of total PM emissions is 4.5%, reduction by 35% (1990-2008)
PRESENTATION OUTLINE

• Introduction

• Sustainability Study

• Sustainability Impact Assessment & Energy Efficiency

• Conclusions
**FUTURE DEVELOPMENT OF EUROPEAN RAIL DIESEL FLEET UNTIL 2020 - LOCOMOTIVES**

- **Declining total number of locos** (13,645 - 9,210)
- Late entry of stage IIIB engines and locos
- Significant number of new IIIA locos after 2012
- In 2020 main part of fleet still UIC II and older

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**Diesel locomotives fleet development (European railway operators, EU27 & EFTA)**

Status: Current fleet is UIC II and older as well as IIIA engines. Approx. 150 new locomotives p.a. Repowering and decommissioning of old vehicles included.

- **UIC II and older**
- **IIIA (incl. remotorisation)**
- **IIIB** (70.2%)

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**Graph data:**

- **2008:** 13,963
- **2009:** 14,014
- **2010:** 14,065
- **2011:** 14,116
- **2012:** 14,167
- **2013:** 14,218
- **2014:** 14,269
- **2015:** 14,320
- **2016:** 14,371
- **2017:** 14,422
- **2018:** 14,473
- **2019:** 14,524
- **2020:** 14,575

**Legend:**

- Blue: UIC II and older
- Red: IIIA (incl. remotorisation)
- Green: IIIB

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**Notes:**

- Declining total number of locos
- Late entry of stage IIIB engines and locos
- Significant number of new IIIA locos after 2012
- In 2020 main part of fleet still UIC II and older
FUTURE DEVELOPMENT OF EUROPEAN RAIL DIESEL FLEET UNTIL 2020 - DMUs

Status: Current fleet is UICII and older and IIIA engines. Approx. 250 new DMUs p.a. Repowering and decommissioning of old vehicles included

• Increasing total number of DMUs (9,100 – 11,100)
• Entry of IIIB DMUs as intended
• In 2020 significant part of fleet with IIIA & IIIB engines
**TOTAL EXHAUST EMISSIONS FROM RAIL DIESEL TRACTION UNTIL 2020 – NO\textsubscript{X} & PM**

**Total NO\textsubscript{X} reduction > 35% until 2020**
- Decreasing loco numbers
- Introduction of IIIA & IIIB
- Stable NO\textsubscript{X} emissions from DMUs despite growing fleet and mileage

**Total PM reduction > 45% until 2020**
- Decreasing loco numbers
- Introduction of IIIA & IIIB
- Stable PM emissions from DMUs despite growing fleet and mileage

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**Graphs:**
- **Total NO\textsubscript{X} exhaust emissions from rail diesel traction**
- **Total PM Exhaust Emissions from rail diesel traction**

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**UIC ENERGY EFFICIENCY DAYS 2014**
SCENARIO: EXHAUST EMISSIONS FROM RAIL DIESEL TRACTION UNTIL 2030 (PM)

A fast commissioning of stage IIIB yields even higher emission reduction than hypothetical "zero emission" stage!
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**IMPACT OF INTRODUCTION OF STAGES IIIA/IIIB**

- **Total NOx reduction ~ 20% until 2020** due to introduction of IIIA & IIIB

- **Total PM reduction ~ 8% until 2020** (introduction IIIA/B)

  Lower than for NO$_x$ (equal PM performance UIC II 
  & IIIA + good PM performance of UIC I)

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**Total NOx emissions with & without introduction of IIIA & IIIB**

- European railway operators, EU27 & EFTA

**Total PM emissions with & without introduction of IIIA & IIIB**

- European railway operators, EU27 & EFTA

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- NOx locomotives
- NOx locos, continuation UIC II
- NOx DMUs
- NOx DMUs, continuation UIC II

- PM locomotives
- PM locos, continuation UIC II
- PM DMUs
- PM DMUs, continuation UIC II
IMPACT OF INTRODUCTION OF STAGES IIIA/IIIB

• Life Cycle Costs for Introduction of Stage IIIA and IIIB
  (cumulated delta costs over 20 years)

• External costs of exhaust emissions from rail diesel traction
  - External costs per ton NO$_x$ and ton PM
  - Weighted European average costs based on performed diesel train mileages per country

• Benefits of exhaust emissions reduction
  - Avoided external costs
  - Per year and cumulated benefits
**Cost/Benefit of IIIA/IIIB**

Cumulated avoided external costs (benefits) vs. cumulated life cycle technology costs from introduction of NRMM stages IIIA/IIIB

European railway operators, EU27 & EFTA

System integration and platform development costs not considered, to be included in any impact assessment (20 platforms for the European rail industry)

In million € 2008 prices

- Cumulated avoided external costs from introduction of IIIA/IIIB vs. UIC II
- Total cumulated technology cost (IIIA + IIIB vs. UIC II) with high cost option
- Total cumulated technology cost (IIIA + IIIB vs. UIC II) with low cost option
ENERGY EFFICIENCY POTENTIALS OF DIESEL TRACTION (ROLLING STOCK & OPERATION)

• Ecodriving & DAS
  – Saving Potentials of 5 - 20 %
  – Higher Potentials for traffic flow management

• Parked Train Management
  – From low tech to system solutions, 3-10% energy savings

• Reuse of Braking Energy
  – Different Storage Options, 3-10% energy savings

• Smart Energy Management
  – Software changes to systemic approaches, up to 10% savings
ENERGY EFFICIENCY POTENTIALS OF HYBRIDS

• High Energy Efficiency Potentials of Hybridization
  – Easy reduction of fuel consumption & CO2 up to 20 %
  – Best for Regional Services & Shunters
  – Reduction of NOx and/or PM but: needs good management strategies

• Energy management strategies can improve the benefits
  – Electrification of auxiliaries is necessary
  – Downsizing and replacement is possible
  – Example Shunter: 1.000 kW-560 kW; PM –73%, NOx –57%, Energy –34%
CONCLUSIONS

• 2020: Significant Reduction: Emissions & and Energy Consumption

• Additional reduction of emissions: Accelerated migration of current technologies into fleet (legislation, incentives) + innovation

• Promising Energy Efficiency Potentials for Diesel Traction Smart Operation Innovative Rolling Stock
Thank you for your attention!

Dr. Roland Nolte, r.nolte@izt.de
ENERGY EFFICIENT DIESEL TRACTION
GB MAINLINE RAIL INITIATIVES

Neil Ovenden - ATOC

Energy Efficiency, the best fuel to move our trains!
GB MAINLINE RAIL IN CONTEXT

- 45% diesel/gasoil traction (by 2012 annual unit miles)
- 55% electric traction (by 2012 annual unit miles)

- Electrification to increase over the next 10 years – by 6,400 track km
GB MAINLINE PASSENGER DIESEL TRACTION

• 3,896 diesel propelled passenger vehicles (2014)
• Diesel/Gasoil: 489Mlitres p.a. (passenger operations - 2012/13)
• Carbon Emissions: 1.34Mtonnes CO$_2$ p.a. (passenger operations - 2012/13)
• future decrease due to diesel fleet reduction & energy initiatives
GB MAINLINE PASSENGER DIESEL FLEET

2014 - 3,896 vehicles

- Short distance, low speed 120km/h max
- Medium distance, 150km/h max
- Long distance, higher speed 200km/h max

2024 - 1,865 vehicles projected

- Short distance, low speed 120km/h max
- Medium distance, 150km/h max
- Long distance, higher speed 200km/h max

UIC ENERGY EFFICIENCY DAYS 2014
GB DIESEL ENERGY INITIATIVES

- Driver Advisory Systems
- New Gearboxes
- Automatic Engine Shutdown
- Fuel Injection & Combustion Improvements
DRIVER ADVISORY SYSTEMS

- Fitted to 8% of cabs now (S-DAS)
- Fitted to 20% of cabs by end 2014 (S-DAS)
- Further significant fitment during 2015 (S-DAS + C-DAS)
- Energy savings >10%
New Gearboxes

- Replace original hydrodynamic DMU gearboxes with 5 speed automatic gearboxes
- Energy savings >10%
OTHER DIESEL EFFICIENCY INITIATIVES

• Automatic Engine Shutdown
  5 – 8% energy saving, dependent on train type, route, timetable

• Fuel Injection & Combustion Improvements
  4% energy saving
CONCLUSIONS

• GB train operators are committed to reducing both traction and non- traction energy consumption and emissions, where they have a business case to do so.

• It is recognised that there is still much more to do.

• GB train operators have delivered and are now reaping the advantages of energy consumption reduction initiatives.
MODELLING OF DIESEL TRACTION CHAIN

WORKSHOP – 18/06/14 – 14H30/16H00

SNCF – CHAUVET FRÉDÉRIC
DIESEL TRACTION CHAIN EXPERT

Energy Efficiency, the best fuel to move our trains!
SUMMARY

1- Energetic and environmental context

2 - Modelling approach

3 - Energetic Macroscopic Representation

4 - Example of application

5 - Conclusions
Energetic and environmental context
ENERGETIC AND ENVIRONMENTAL CONTEXT

- Decrease of amount of fossil energies
- Increase of cost of fossil energies
- Problems with global warming and health impact
  - Evolution of the pollutant limits for diesel engine
  - Decrease of NOX and PM emissions imposed by UIC

⇒ Necessity to reduce the fuel consumption and exhaust emissions of diesel locomotives and DMU
ENERGETIC AND ENVIRONMENTAL CONTEXT

• SNCF want to reduce his energy consumption about 20% before 2020

• The fuel consumption represents 21% of the total energy consumption

• Different solutions exist to reach these objectives
  – Stop and Start
  – ESS
  – Heat waste recovery

• Assessment of the return of investment

⇒ Necessity to use modelisation of diesel traction chain
Modelling Approach of diesel traction chain
MODELLING APPROACH

• Train is a system in interaction with his environment
• Train is composed by different sub-systems
• Train is managed by physical laws
• The future trains will have different energy sources
• The future train need management of energetic exchanges which will be more complex

⇒ Different approaches of modelling are possible
**MODELLING APPROACH**

- Different possibilities to describe a system:
  - Structural
  - Functionnal
- Different possibilities to connect subsystem:
  - Causal
  - Non-causal
- Different methods to compute the model:
  - Forward approach
  - Backward approach

➡️ A lot of possibilities exist and depend on the aim which is researched
EMR: PURPOSE, PRINCIPLE AND ADVANTAGES

• E as Energetic:
  – Modelling energetic interactions
    • System / environment
    • Between sub-systems
    • Action and reaction links
• M as Macroscopic :
  – Possibility to adjust the model in accordance with the knowledge of the system
• R as Representation
  – Graphic representation
EMR: PURPOSE, PRINCIPLE AND ADVANTAGE

• The principles of EMR are:
  – Systemic representation
  – Causal approach
    • Outputs are an integral function of inputs
• The advantages of EMR are:
  – Graphic representation
  – « Same language » between specialists
  – Possibility to create library of models (data bases)
  – No specific solver (causal approach)
  – Deduction of the control laws by inversion of the model
**Example: DC Motor**

**Action 1:** Application of Voltage $U$

**Reaction 1:** Current $I$

**Power input:** $\text{Action 1} \times \text{Reaction 1} = U \times I$

**Action 2:** Application of load $C$

**Reaction 2:** Rotation speed $\Omega$

**Power output:** $\text{Action 2} \times \text{Reaction 2} = C \times \Omega$
### EMR: Model Representation

**Causes**
- Action
- Reaction

**Physical Function**

**Effects**
- Action
- Reaction

\[ S = \int_{0}^{\tau} f(E) \, dt \]

<table>
<thead>
<tr>
<th>Source Element (Energy Source)</th>
<th>Accumulation Element (Energy Storage)</th>
<th>Indirect Inversion (Closed-Loop Control)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mono-Physical Conversion Element</td>
<td>Mono-Physical Coupling Element (Energy Distribution)</td>
<td>Direct Inversion (Open-Loop Control)</td>
</tr>
<tr>
<td>Multi-Physical Conversion Element</td>
<td>Multi-Physical Coupling Element (Energy Distribution)</td>
<td>Coupling Inversion (Energy Criteria)</td>
</tr>
<tr>
<td>Amplification Element</td>
<td>Switching Element</td>
<td>Inversion of a Switching Element</td>
</tr>
</tbody>
</table>

**Images:**

- Source element (energy source)
- Accumulation element (energy storage)
- Indirect inversion (closed-loop control)
- Direct inversion (open-loop control)
- Coupling inversion (energy criteria)
- Inversion of a switching element
**EMR: MODELLING TOOL**

- The EMR model is implemented in a modelling tool
- Generally, MATLAB SIMULINK is used
**Example: DC Motor**

- An energy source provides power to an electric motor to move a load
- The electric motor involves a shaft after a reductor
- Define the control laws to have a rotation speed whatever the load

![Diagram of DC Motor System]

**Diagram Explanation**
- **Energy Source (SE)** provides power to the system.
- **Inductance (I)** and **Condenser (C)** store and transfer energy.
- **Voltage Modulator (Mod U)** controls the voltage applied to the motor.
- **Motor (M)** converts electrical energy into mechanical energy, which is then transmitted to the load.
- **Reducer (R)** reduces the speed of the motor's output.
- **Environment (Environ)** represents external factors affecting the system.

**Control and Variables**
- **Control Commande** ensures the desired rotation speed is maintained.
- **Voltage Modulator** controls the input voltage to the motor.
- The system involves control laws for precise operation, including **PID Control** for accurate speed management.

**Mathematical Notations**
- **SE** (Energy Source)
- **I** (Inductance)
- **C** (Condenser)
- **Mod U** (Modulator)
- **M** (Motor)
- **R** (Reducer)
- **Environ** (Environment)

**Variables**
- **U** (Voltage)
- **I** (Current)
- **M** (Motor)
- **R** (Reducer)
- **Environ** (Environment)

**Control and Efficiency**
- **Control PID** for optimal performance.
- **Speed Demand by Operator** to adjust the system based on user input.
- **Measure of the Rotation Speed** to monitor system performance.

**Inversion Control** and **Ωm Measured** for enhanced system efficiency.
Example of Application:
Y9000 ECOLOC
PRESENTATION OF THE Y9000

- Small shunter
- Diesel engine
- 3 hydraulic circuits for auxiliaries
PRESENTATION OF ECOLOC SYSTEM

- Stop and Start system

- Objectives of ECOLOC system:
  - Reduction of the fuel consumption
  - Reduction of CO\textsubscript{2} emissions
  - Reduction of exhaust emissions
  - Reduction of cost maintenability based on the functioning time interval
  - Reduction of the noise

- Propose to the drive to stop the diesel engine
PRESENTATION OF ECOLOC SYSTEM

No major default

No default with compressor

ECOLOC system in normal mode

No major default

Diesel engine
started

No air-conditioning demand

Diesel engine temperature
> 50°C

Air pressure > 9.2 bar

Fuel temperature
> 20°C

Battery voltage
> 24 V

Diesel engine
started

Diesel engine
temperature
> 50°C
EMR OF THE AUXILIARY CIRCUITS OF Y9000
RESULTS OF MODELLING

**Fuel consumption**

- Without ECOLOC: -30%
- ECOLOC - V1: -41%
- ECOLOC - V2

**Working time**

- Without ECOLOC: -50%
- ECOLOC - V1: -65%
- ECOLOC - V2
Conclusions
• SNCF make the choice to used EMR to:
  – Optimise the management of diesel traction chain
  – Reduce fuel consumption and exhaust emission
  – Reduce the cost of maintability due to the maintenance policy based on functionning time intervals

• Diesel traction chain are more and more complex

• The future hybrid solutions need optimization of the control of energetic exchanges
Thank you for your attention