Comparison of European TramTrain-Projects with the Kassel RegioTram

SINTROPERHER
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Authors

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Sources

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Land Hessen and Public Transport Authorities
The NVV presents himself

Settlement scheme

- City of Kassel
  (195,000 inhabitants)

- Municipalities
  (10 – 30,000 inhabitants)
Abstract

- Who is NVV?
- Why this study?
- Approach
- TramTrain-Definition
- Selected projects
- Rolling stock overview
- Selected parameters and indicators
- Results
- Conclusions for the Kassel RegioTram
- General Conclusions
Why this study?

- Idea: to create a benchmarking approach for Tram-Train projects …
- …to look beyond one’s own nose
- Position of the Kassel project compared to other projects
- Gain a more detailed look on vehicle procurement
- Collect ideas and draw conclusions for further development and improvements of our project
- Share experiences and ideas with related projects
Approach

- **Limited time and financial resources**
- In Stage One a **desktop research** is considered sufficient
- Selection of **appropriate projects**
- Still few projects in operation – therefore necessity to include also planned projects
- Selection of key **parameters and indicators**
- Focus on **vehicle procurement**
- **No claim** that selected projects and parameters are **exhaustive**
- Beware: some figures are uncertain/incomplete and need verification
- Study performed by Axel Kuehn, Light Rail Expert
TramTrain-Definition

- TramTrain still a very young genre, thus no binding international definition yet

- Basically one notices a German and a French “definition”:
  
  **German:** Mixed operation of light-rail and heavy rail vehicles on tram and railway infrastructure (normally paired with dual mode technology)
  
  **French:** Operation of light-rail vehicles with speeds higher then 70km/h (usually 100km/h)

- Important: The French definition does not limit TramTrain to track-sharing light rail / heavy rail and / or use of dual-mode technology! It includes also interurban fast tramways.
Selected projects

- Karlsruhe + Heilbronn (D)
- Saarbruecken (D)
- Chemnitz (D)
- Braunschweig (D)
- Aulnay-Bondy (F)
- Mulhouse (F)
- Nantes (F)
- Lyon (F)
- Alicante (E)
- Porto (P)
- Rijn-Gouwe-Lijn (NL)
- RandstadRail (NL)

14 Cities/Regions (including Kassel) from 5 European countries
40 Corridors/Single projects (eg Karlsruhe + Heilbronn 17 corridors!)
Kassel RegioTram (4 corridors)

Present Stage, 2007 – Dec 2012

- 4 lines, at least 1 train per hour
- 3 new stations
- Express service by “conventional” trains, 0.5–1 train per Hour
- Treysa line not part of review!
Kassel RegioTram (4 corridors)

Final Stage, Starting Dec 2012

- 3 lines, 2 trains per hour
- 2 additional stations
- Express service by “conventional” trains, 0.5–1 train per hour
Kassel RegioTram – the 4th corridor

Kassel – Hessisch Lichtenau

- A conversion project
- The predecessor of Kassel’s “real” TT-approach
- Characteristics of a “regional tramway” (vehicle, maximum speed etc)
- A very innovative approach to convert a freight railway route
Selected projects: Karlsruhe (15 corridors) + Heilbronn

- Starting point about 1960 with the linking of „Albtalbahn“ railway to tramway network
- TramTrain operation on DB main lines started from 1991
- Now about 600km TramTrain-network on DB-tracks, leased and own tracks

Source: AVG (updated)
Selected projects: Karlsruhe (15 corridors) + Heilbronn

- 122 +30 TT-vehicles
- Only system using middle-floor (55cm) entrance height
- Track-sharing both TT vs railway and TT vs low-floor tramway
- Saturation of city-centre corridor + high percentage of 75m trains have led into underground project!

- Estimated total costs 530 Mio € of which about 400 Mio € related to the tunnel by-pass! “Cheap and easy?”
Selected projects: Karlsruhe + Heilbronn (2 corridors)

- Scheme connected to AVG network via Bretten-Eppingen and operated by AVG
- East-West corridor Eppingen-Heilbronn (26km) and Heilbronn-Oehringen (27km) opened in two steps 2001 and 2004/2005
- North-South corridor planned; Southern extension currently uncertain

Source: www.stadtbahn-heilbronn.de
Selected projects: Saarbruecken (2 corridors)

- First section Saarbruecken-Sarreguemines (France) opened 1997; included 5km of new urban tramway and 14km railway
- Northern section still not completed – Riegelsberg opened 2009
- 28 vehicles (FLEXITY LINK, first low-floor TT-vehicle) ordered in 1995 and delivered in 1997/98 for the complete project – huge vehicle surplus for long period of time!
Selected projects: Chemnitz (3 corridors)

- Pilot project Chemnitz-Stollberg opened in late 2002 - in principle a “conversion” project.
- Electrification with 750 V DC
- Railway status kept but private infrastructure owner/manager
- 6 VARIOBAHN “tramway” vehicles used, maximum speed 70km/h
- Next phase includes “real” TramTrain operation with Diesel Hybrid TT-vehicles to Burgstädt and Hainichen with connection to urban network, 10 vehicles to be ordered in 2010

Source: Citybahn Chemnitz
Selected projects: Braunschweig (5 corridors)

- Several (long) un-electrified railway corridors (Uelzen 96 km!) linked to urban tramway network
- Planned opening: 2014?
- Special case: Existing tramway 1100mm gauge > 3-rail track
- New urban/tramway track in Salzgitter-Lebenstedt
- Estimated project costs 279 Mio € (2006)
- 30 Diesel hybrid vehicles required, future vehicle type unknown yet
Selected projects: Aulnay - Bondy (1 corridor)

- TramTrain „shuttle“ between RER-nodes, tangential sub-urban service in Greater Paris
- No connection to main line railways at either end – TT-operation completely separated
- Operated by SNCF, 6min frequency
- 25 kV AC electrification
- 8km length – 280,000 inhabitants in corridor (!)
- 120 Mio € costs
- 15 vehicles (Siemens AVANTO)

Source: www.ter-sncf.com (up, adapted), SNCF/Transilien (bottom)
Selected projects: Mulhouse (1 corridor)

- New urban tramway + add-on TT-corridor to Thann/Kruth; tramway opened 2006, TT will open late 2010 to Thann
- Connected to tramway network
- 22.5 km (Thann); 39.0 km (Kruth)
- 147 Mio € (Thann)
- 12 vehicles (AVANTO)
Selected projects: Nantes (2 corridors)

- Nantes-Chateaubriant corridor; re-opening of a 64km railway closed in 1980, operation start foreseen for 2012.
- Not connected to urban tramway, terminating in main railway station
- 200 Mio €
- 15 vehicles (DUALIS) – also for Clisson corridor (replacement for railway rolling stock).

Source: www.reouverture-nantes-chateaubriant.fr
Selected projects: Lyon (3 + 1 corridors)

- “L’Ouest Lyonnais“-project: Lyon-Sain Bel, Lyon-Brignais, Lyon-Lozanne
- Planned for opening 2011-2015 in steps
- Not connected to urban tramway
- 55km network
- 320 Mio €
- 34 vehicles (DUALIS), 24 so far ordered for Sain Bel + Brignais

Source: www.projet-ferroviaire-ouest-lyonnais.fr
Selected projects: Lyon (3 + 1 corridors)

- Rhonexpress (LESLYS) airport link; joint running with tramway to Meyzieu, but using different rolling stock with 100km/h maximum speed and infrastructure adapted for over-taking
- Operational since August 2010
- 23km (15km LEA tramway)
- 120 Mio € (40 Mio € public + 80 Mio € private – PPP!) + 172 Mio € for LEA tramway corridor
- 6 vehicles (TANGO EXPRESS)

Source:
www.lyon-en-lignes.org
(up, adapted)
www.tramtom.de (left)
Selected projects: Alicante (1 corridor)

- Scheme is combining local tramway and regional express train (TramTrain) features – also visible by use of different vehicles with 70 and 100km/h
- Operational since 2006 (TT)
- Denia (planned) 103km; Benidorm (operational) 43km
- ??? Mio €
- 9 vehicles (VOSSLOH 4100)
Selected projects: Porto (2 corridors)

- Opened in steps from 2002-2006 - total network 70km (yet without Ismai-Trofa 10km, under construction)

- Former narrow gauge railway corridors to Povoa de Varzim and Ismai (Trofa) converted to light rail (full double track!) and combined with new city tramway, 30 km / 26.5 km from Trindade station

- Electrification with 750 V DC

- 573 Mio € costs (only regional infrastructure outside core section including Trofa – total 43km)

- 30 vehicles (FLEXITY SWIFT, 100 km/h) in addition to tramway rolling stock

Source: Metro de Porto
Selected projects: Rijn-Gouwe-Lijn (1 corridor, East)

- Project combines urban tramway from in Leiden and to the coast (West) with TT-operation from Leiden to Alphen and Gouda (East)
- Planned opening 2015?
- Test operation with FLEXITY SWIFT (A32) vehicles from 2003-2009
- 28 km Leiden-Centre - Gouda
- Project costs: 335 Mio € (East part only, estimated)
- Future vehicle type unknown yet

Source: www.rijngouwelijn.nl
Selected projects: RandstadRail (2 corridors/lines)

- RandstadRail project combining light rail (TramTrain) connection The Hague-Zoetermeer with metro connection to Rotterdam

- Two light rail lines using tramway infrastructure in The Hague and running out to Zoetermeer on former heavy rail infrastructure; 27km / 29.5km

- Project costs: 1 Billion € (including metro)- approx. 500 Mio € for The Hague part (still including metro related costs)

- 50 vehicles (REGIO CITADIS)

Source: www.randstadrail.nl
Rolling stock overview

Suppliers and products:

- ALSTOM with DUALIS (and REGIO-CITADIS?)
- BOMBARDIER with FLEXITY SWIFT
- SIEMENS with AVANTO?
- VOSSLOH with 4100 vehicle (Alicante)
- STADLER with TANGO EXPRESS
- CAF with (type Cadiz?)
ALSTOM DUALIS (REGIO-CITADIS)

- Pays de la Loire (Nantes), 7 vehicles and Region Rhone-Alpes (Lyon), 24 vehicles, ordered 2007, 8 more for Nantes in 2009
- Nantes 750V DC / 25 kV AC, Lyon 1500V DC / 25kV AC
- 42m length, 2.65m width; seated capacity: 95
- Further options for Strasbourg and Ile-de-France, total frame of SNCF contract 200 vehicles

Source: Alstom
ALSTOM REGIO-CITADIS

- ordered 2002 by NVV Kassel, 28 vehicles
- 18 vehicles 750V DC / 15 kV AC, 10 vehicles 750V DC / Diesel
- 36.7m length, 2.65m width; seated capacity: 100
- ordered 2004 by HTM for RandstadRail, 50 vehicles 600V / 1500 V DC
- 36.7m length, 2.65m width; seated capacity: 84 (more doors)
BOMBARDIER FLEXITY SWIFT

- Porto (750V DC, 100km/h), 30 vehicles ordered 2006
- Karlsruhe (750V DC / 15kV AC, 100 km/h), 30 vehicles ordered 2009
- Porto vehicle low-floor 35cm, Karlsruhe vehicle medium-floor 55cm
- 37m length (BOStrab!), 2.65m width; seated capacity: 100

Source: Bombardier/KVV (right)
SIEMENS AVANTO

- Aulnay-Bondy (750V DC / 25kV AC, 100km/h), 15 vehicles ordered 2002
- Mulhouse (750V DC / 15kV AC, 100 km/h), 12 vehicles ordered 2006
- Low-floor vehicles
- 37m length, 2.65m width; seated capacity: 80
VOSSLOH 4100

- Alicante (750V DC, 100km/h), 9 vehicles ordered 2003
- Mallorca (750V DC, 100 km/h), 6 vehicles ordered 2009
- FEVE/Leon (750 V DC, 100km/h), 4 vehicles ordered 2010
- 37m length, 2.55m width; seated capacity: 92

Source: Vossloh
STADLER TANGO EXPRESS

- Rhonexpress Lyon (750V DC, 100km/h), 6 vehicles ordered 2006
- Low-floor
- 27m length, 2.55m width; seated capacity: 76
- Interesting feature: Double traction of 55m can use 40m platforms due to door configuration

Source: www.tramtom.de
TRAMTRAIN ROLLING STOCK COST TREND

TramTrain costs per order year [€/m²]

37m x 2.65m
≈100m²

Order year
TRAMWAY ROLLING STOCK COST TREND

Tramway costs per order year [€/m²]

Order year

37m x 2.65m
≈100m²
EN15227 impact on TramTrain

- Original TramTrain idea (Karlsruhe > LNT-regulations) has been to compensate lower passive safety by higher active safety (tramway braking!)

- This lead to acceptance of 600kN crashworthiness for TT-vehicles in mixed railway operation (with operational limitations: max 95km/h etc)

- Railway: 1500kN (UIC)    Tramway: 200-400kN

- No general approval of TT-vehicles in other countries, case-based approach! Safety has to be demonstrated for each system/line!

- SAFETRAIN and SAFETRAM EU-projects led into a new European standard regarding crashworthiness of railway vehicles > EN15227

- Crash scenarios!

- Depending on country specific exemptions new orders have to respect the new standard!
EN15227 impact on TramTrain

Crashworthiness of Rail Vehicles

Passive safety basic elements

*European railway vehicle categories (prEN 15227, Table 1)*

<table>
<thead>
<tr>
<th>Category</th>
<th>Definition</th>
<th>Examples of vehicle types</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-I</td>
<td>Vehicles designed to operate on TEN routes, international, national and regional networks (which have level crossings)</td>
<td>Locomotives, coaches &amp; fixed units</td>
</tr>
<tr>
<td>C-II</td>
<td>Urban vehicles designed to operate only on a dedicated railway infrastructure, with no interface with road traffic</td>
<td>Metro vehicles</td>
</tr>
<tr>
<td>C-III</td>
<td>Light rail vehicles designed to operate on urban or regional networks, in track-sharing operation, and interfacing with road traffic</td>
<td>Tram trains, periurban tram</td>
</tr>
<tr>
<td>C-IV</td>
<td>Light rail vehicles designed to operate on dedicated urban networks interfacing with road traffic</td>
<td>Tramway vehicles</td>
</tr>
</tbody>
</table>

Source: DB
EN15227 impact on TramTrain

Crashworthiness of Rail Vehicles

Passive safety basic elements

European railway design collision scenarios outline (prEN 15227, Table 2)

<table>
<thead>
<tr>
<th>Design collision scenario</th>
<th>Collision obstacle</th>
<th>Operational characteristics of requirement</th>
<th>Collision Speed - km/h</th>
<th>Collision partner and conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td>C-I</td>
<td>C-II</td>
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<tr>
<td>1</td>
<td>Identical train unit</td>
<td>All systems</td>
<td>36</td>
<td>25</td>
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<tr>
<td>2</td>
<td>80-tons wagon</td>
<td>Mixed traffic with vehicles equipped with side buffers</td>
<td>36</td>
<td>Na</td>
</tr>
<tr>
<td>3</td>
<td>120-tons regional train</td>
<td>Mixed traffic with vehicles with a central coupler</td>
<td>na</td>
<td>Na</td>
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<tr>
<td>3</td>
<td>15-tons deformable obstacle</td>
<td>TEN &amp; similar operation with level crossings $V_{le} \leq 110$</td>
<td>na</td>
<td>25</td>
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<tr>
<td>4</td>
<td>Small, low obstacle</td>
<td>Obstacle deflector requirements to be achieved</td>
<td>See table 3</td>
<td>See table 3</td>
</tr>
</tbody>
</table>

Source: DB
EN15227 impact on TramTrain

- For a Category I heavy rail vehicle fulfilment of the crash scenarios means a crashworthiness of about 3000kN compared to 1500kN requested before!

- Future TT-vehicles will likely need to get to 800-1000kN?

- Older TT-rolling stock, i.e. the REGIO CITADIS, requires for new orders heavy re-engineering and will no more be available “as is”.

- Even new DUALIS only partial fulfilment (exemptions!) 

- Further cost increases to be expected!
Selected parameters and indicators

- Evaluation and comparison based on radial lines / corridors, thus from city centre to region (diametrical lines cut in two!)

- Five groups of parameters / indicators:
  
  **General corridor** description (length, number of stops, average stop distance, railway share, electrification, connection to urban network)

  **Operational features** (mixed operation with railway/tramway, travel time to city centre, average speed, operation times weekdays, maximum frequencies)

  **Rolling stock** features (type, order year, number, dimensions, speed, motorization, crashworthiness, capacity, double/multiple traction)

  **Demand** features (population in corridor without main city, passenger numbers before/after respectively before/planned)

  **Cost** features (infrastructure, rolling stock and operation)
## Results: Operational Overview

<table>
<thead>
<tr>
<th>Destination</th>
<th>Mixed operation with railway</th>
<th>Mixed operation with tramway</th>
<th>Connection to city/tramway network</th>
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<tbody>
<tr>
<td>Karlsruhe Marktplatz-Stutenau/Spöck</td>
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<td>Karlsruhe Marktplatz-Rheinstetten</td>
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<td>Karlsruhe Marktplatz-Bad Herrenalb</td>
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<td>some freight</td>
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<td>Karlsruhe Marktplatz-Ilmenau</td>
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<td>Karlsruhe Marktplatz-Hochstetten</td>
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<td>Karlsruhe Marktplatz-Rastatt-Freudenstadt Hbf</td>
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<td>Karlsruhe Marktplatz-Rastatt-Baden-Bühl (Achern)</td>
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<td>Karlsruhe Marktplatz-Brettten (Eppingen)</td>
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<td>Karlsruhe Marktplatz-Würth Badepark</td>
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<td>Karlsruhe Marktplatz-Porzheim</td>
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<td>Karlsruhe Marktplatz-Porzheim-Mühlacker-Bietigheim/8issingen</td>
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<td>Karlsruhe Hbf-Bruchsal-Menzingen</td>
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<td>Karlsruhe Hbf-Bruchsal-Odenheim</td>
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<td>Bruchsal-Mühlacker</td>
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<td>Karlsruhe Marktplatz-Heilbronn Rathaus</td>
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<td>Karlsruhe Marktplatz-Heilbronn Rathaus (Express)</td>
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<td>Karlsruhe Hbf-Heilbronn Rathaus (Sprinter)</td>
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<td>Heilbronn Rathaus-Schwaigern (Epptingen)</td>
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<td>Heilbronn Rathaus-Weinsberg-Öhringen</td>
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<td>Saarbrücken Hbf-Sarreguemines</td>
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<td>Saarbrücken Hbf-Riegel/Güchenbach</td>
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<td>Saarbrücken Hbf-Lebach Bf</td>
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<td>freight?</td>
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<td>Kassel Königsplatz-Hessisch Lichtenau</td>
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<td>possible</td>
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<td>Kassel Königsplatz-Wolfgang</td>
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<td>Kassel Königsplatz-Velten</td>
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<td>Kassel Rathaus-Holgersmar (Warburg)</td>
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<td>Chemnitz Hbf-Stolberg</td>
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<td>Chemnitz Hbf-Burgstädt</td>
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<td>Bad Harzburg - Braunschweig Nord Bf</td>
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<td>Gifhorn (Triangel) - Braunschweig Nord Bf</td>
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<td>Wolfenbüttel (Schöppenstedt) - Braunschweig Nord Bf</td>
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<td>Salzgitter - Braunschweig Nord Bf</td>
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<td>Goslar - Braunschweig Nord Bf</td>
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<td>Nantes-Crison</td>
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<tr>
<td>Nantes-Chateaubriant</td>
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<td>very limited</td>
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<td>Mulhouse-Thann</td>
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<td>Mulhouse-Thann-Kruth</td>
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<td>Aulnay-Bondy</td>
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<td>Lyon Part Dieu - Satolas Airport (Randstadrail)</td>
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<td>Lyon-Sain Bel</td>
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<td>Lyon-Lozanne</td>
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<td>Porto Trindade-Povo</td>
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<td>Porto Trindade-Povo (Express)</td>
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<td>Porto-Trindade-Trofa</td>
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<tr>
<td>Alicante Luceros-Benidorm (Express)</td>
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<td>Alicante Mercado-Denia (Express)</td>
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<td>Alicante Luceros-Venta Lanuza</td>
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<tr>
<td>The Hague/Loosduinen-Zoetermeer Centrum-West (Randstadrail)</td>
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<td>The Hague/De Uithof-Zoetermeer Javalaan (Randstadrail)</td>
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<tr>
<td>Leiden-Alphen-Gouda (RGL East)</td>
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</tbody>
</table>
Results: Operational Parameters
Share of railway use (km Railway/km tramway)
Results: Corridor Description
Length of radial corridors / routes
Results: Route Parameters
Average stop distance
**Results: Parameters of Level of Service**

**Average corridor / service speed**
Results: Level of service parameters
Travel time to centre [min]
Results: Level of service parameters
Operation time per day
**Results: Level of Service parameters**

**Maximum frequency / trains per hour and direction**

<table>
<thead>
<tr>
<th>Location</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berlin</td>
<td>10</td>
</tr>
<tr>
<td>Munich</td>
<td>8</td>
</tr>
<tr>
<td>London</td>
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<tr>
<td>Paris</td>
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<tr>
<td>Rome</td>
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<td>Tokyo</td>
<td>1</td>
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<tr>
<td>Sydney</td>
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</tbody>
</table>

![Graph showing frequency of trains per hour and direction across various cities.](image)
Results: Potential demand indicators
Population / inhabitants per route-km
Results: Infrastructure Costs (1)

- Difficult comparison – projects are very different …
- Rather expensive projects (Porto, Randstad Rail)
- Rather cheap projects (Kassel, Chemnitz)
- Main distinction to be made between projects that rely on existing urban or railway infrastructure …
- … and those that need to build an urban tramway corridor (Saarbruecken, Mulhouse, Heilbronn) or refurbish railway infrastructure (Nantes, Porto)
- Topic should be considered more deeply
Results: Infrastructure Costs (2)

As an Example: Heilbronn

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Eppingen–Heilbronn Hbf</td>
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<td>2,4</td>
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<td>Heilbronn–Ohringen</td>
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<td>Zaberfeld–Lauffen</td>
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<td>33,6</td>
<td>1,9</td>
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<td>Lauffen–Heilbronn</td>
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<td>Gesamtnetz</td>
<td>139,2</td>
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</tbody>
</table>

Source: Naumann / Stadtverkehr 10/04
Summary and findings for the Kassel RegioTram (1)

- The Kassel Project combines the typical advantages of the Tram-Train approach:
  - high average velocities
  - Improved accessibility of regional settlement areas by new stations
  - Improved level of service (from Dec 2012)
- A well designed system that yielded remarkable increases in transport demand since 2007 (+60%), …
- … and we hope for another push in passenger demand introducing a clear 30 minutes interval in Dec 2012
- …yet, compared to other projects the indicators of potential demand are in the lower third → Kassel has to get the most of the potential demand (by line extensions in Kassel city and region, marketing)
Summary and findings for the Kassel RegioTram (2)

- The Kassel system was deliberately confined to a 30/40 min – isochrone
- i.e. most of the passengers have a trip length of less than 30 minutes
- The Kassel TT-system requires a cooperation with „conventional“ trains → prerequisite for exhausting the potential demand
- Chances of expansion are limited → hardly any chance to re-order Kassel RegioCitadis type
- additional vehicle procurement depends on realization of related projects (e.g. Braunschweig) → different vehicle types
- New vehicle types will be heavier → problems in the tramway network
Summary and findings for the Kassel RegioTram (3)

- The Kassel Project profited from the early 2000s enthusiasm of planning authorities and vehicle manufacturers
- Comparatively low vehicle procurement costs
- But: TT is not a rationalization project → operation costs are above those of conventional railway lines
- Any opportunity to reduce operation costs has to be taken
Summary and findings – Vehicle procurement (1)

- Rolling stock suppliers are no more eager to win reference projects by low offers as in the early 2000s
- The TramTrain vehicle market now is strongly influenced by the effects of the new EN15227 crash-standard
- Considerable price gap between “conventional” light rail and TT-vehicles (2010: 48,000 €/m² - 36,000 €/m² --- 2002: 38,000 €/m² - 28,000 €/m²)
- Some projects in Spain and France yielded extremely high procurement prices due to low vehicle numbers
- Only an order size of more than 30 vehicles ensures a reasonable price level → but most TT-projects suffer from low procurement numbers
Summary and findings – Vehicle procurement (2)

- The idea of Diesel-TT finds hardly any follower (Aarhus and Braunschweig now being re-considered)

- Indications for further vehicle cost increases compared to standard AC/DC TT-vehicles

- The **twofold price gap** enforces for those projects either a
  - project resizing or
  - a shift to conventional train service or
  - “one system” light rail service
General summary and findings (1)

- the TT-approach offers a variety of light rail solutions otherwise not possible, ...

- ... often customized solutions, some are very expensive

- ... often starting as a supplement to existing tramway schemes

- TT-approach mainly to be found in minor/medium sized conurbations, in some cases as tangential connections in large agglomerations (Aulnay-Bondy, Randstad)

- In most cases TT is a means to extend the accessibility of minor/medium sized conurbations → enhancing the competitiveness of regions

- Corridors / lines beyond the 30 Minutes Isochrone → may raise comfort issues
General Summary and Findings (2)

- The Karlsruhe/Heilbronn TT-network is by far the biggest system, showing a variety of operational combinations (i.e. stop-/express-TT, creative frequency types) and procurement features (i.e. lease of infrastructure).

- The Karlsruhe/Heilbronn TT-network is for many lines beyond the 30 Minutes Isochrone.

- It is above the “critical size” needed to yield economically feasible vehicle procurement prices.

- The most rapid development to be found in France → partly due to municipal decision and financing autonomy.

- … but not yet clear whether the TT-approach will leave its niche.
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