G7 ITALIA 2024

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## G7 Transport Academic Workshop

# *Resilience, robustness and redundancy – principles for developing future infrastructures*

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Wednesday, 10th April 2024 - Aula Magna "Carassa e Dadda"
Politecnico di Milano, Bovisa Campus, Milan (Italy)

# Agenda

- **Notions and concepts**
- Case studies
  - Road Infrastructures
  - Railways
  - Public transport networks
  - World wide waterways and logistics
- Special purpose infrastructures?
- Network topology measures?
- Summary

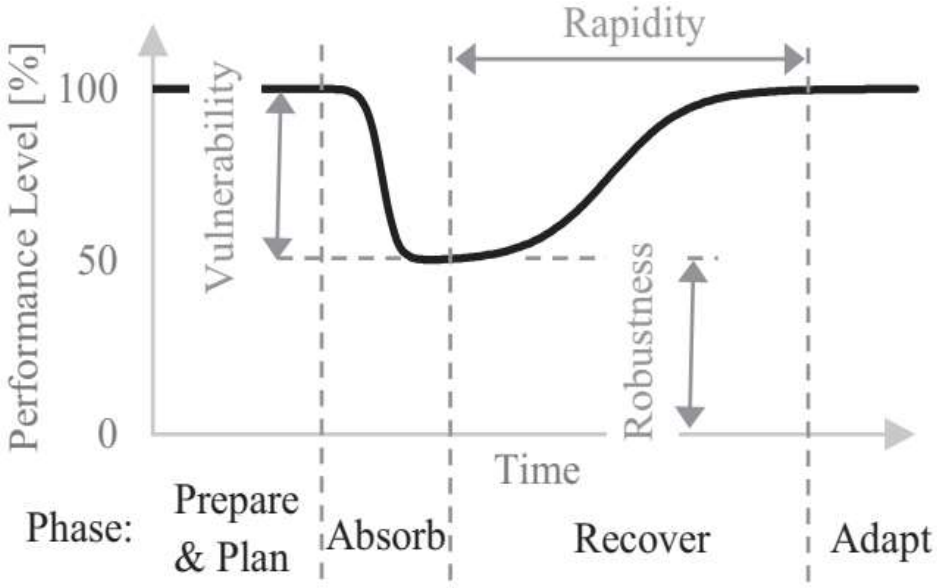
# Notions and concepts

**Robustness:**

How much performance is left after an incident?

**Resilience:**

How quick can a system recover??




Demmer et. al. (2022) based on Bruneau et. al. (2003)

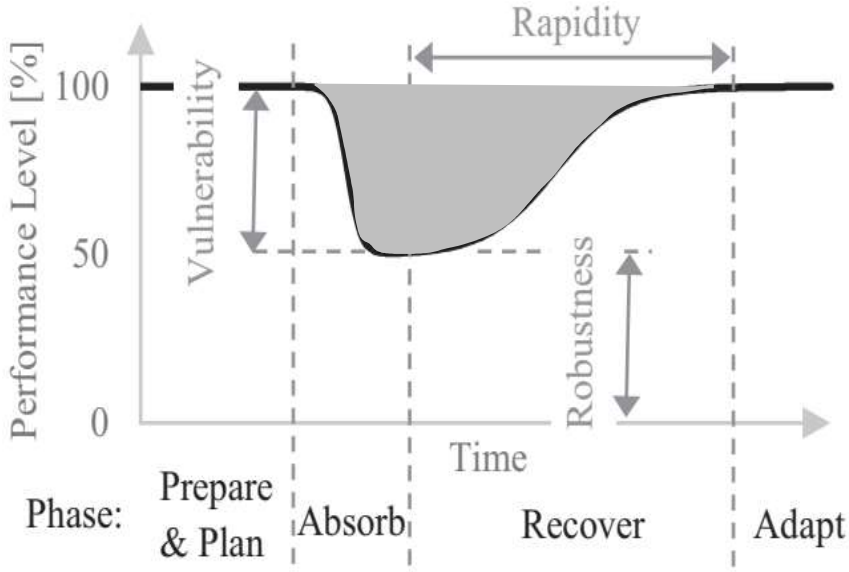
# Notions and concepts

$$Damage = \int_{Absorb+Recover} Performance\ Level\ (Time)\ \ dTime$$

$$Risk = Probability\ \cdot Damage$$

**Why do we need the concept of resilence?**

- It is not possible to be 100% robust
- Perception of different risks changes
- Unpredicability (robust against what?)




Demmer et. al. (2022) based on Bruneau et. al. (2003)

# Super/hyper/logical/infrastructure…. networks

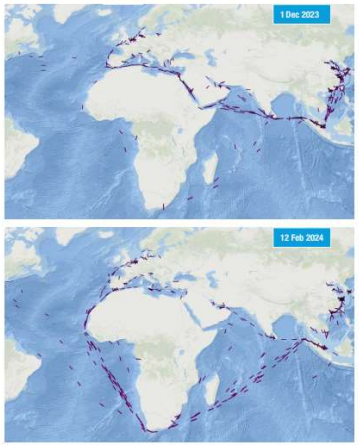
- Infrastructure is only the foundation on which the actual traffic is based
- Different types of networks intertwine
  - Trip chains in public transport
  - Supply chains in freight transport
- Errors in the single networks could propagate in the other
- Networks can also substitute each other
- Sparse nodes and links with high utilization are the most critical ones


https://www.bvg.de/de/verbindungen/netzplaene-und-linien

https://sourcemap.com/news/what-is-supply-chain-mapping

# Critical nodes and links

- There are critical nodes  and links in logistics, value added, public transport, infrastructure …. networks




UNCTAD (2024)

BUSINESS

**Hanjin Shipping's Troubles Leave $14 Billion in Cargo Stranded at Sea**

Owners strive to recover their goods and get them to customers in wake of Hanjin Shipping bankruptcy filings

*By Costas Paris and Erica E. Phillips*

Updated Sept. 7, 2016 7:49 pm ET | WSJ PRO

https://www.wsj.com/articles/billions-in-cargo-remains-stranded-at-sea-1473285117

- Hypothesis: If each actor minimized its maximum critical network components, the overall network becomes more robust and resilient

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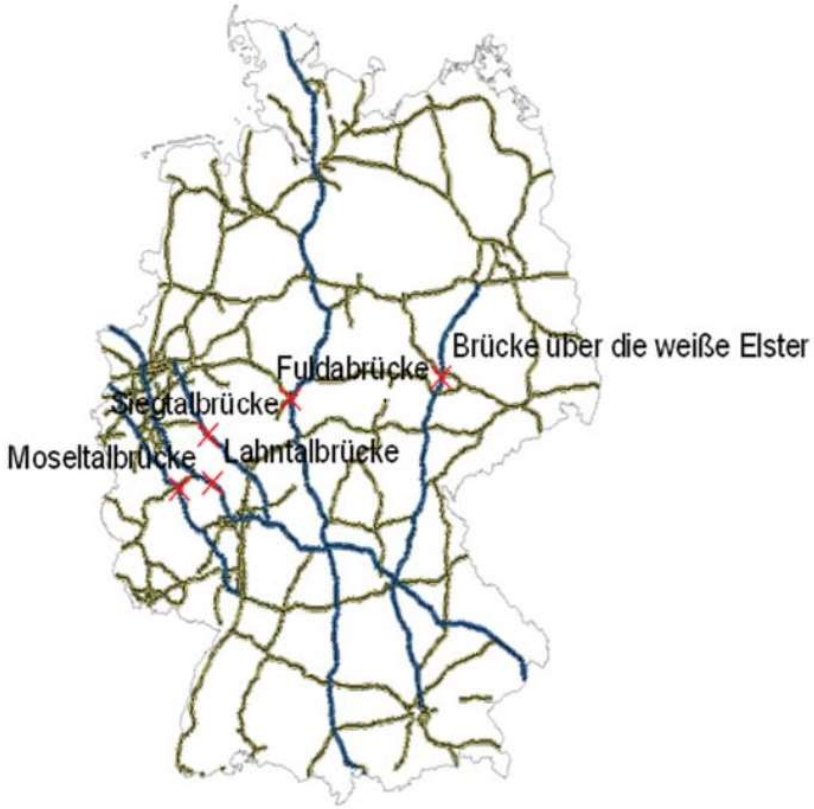
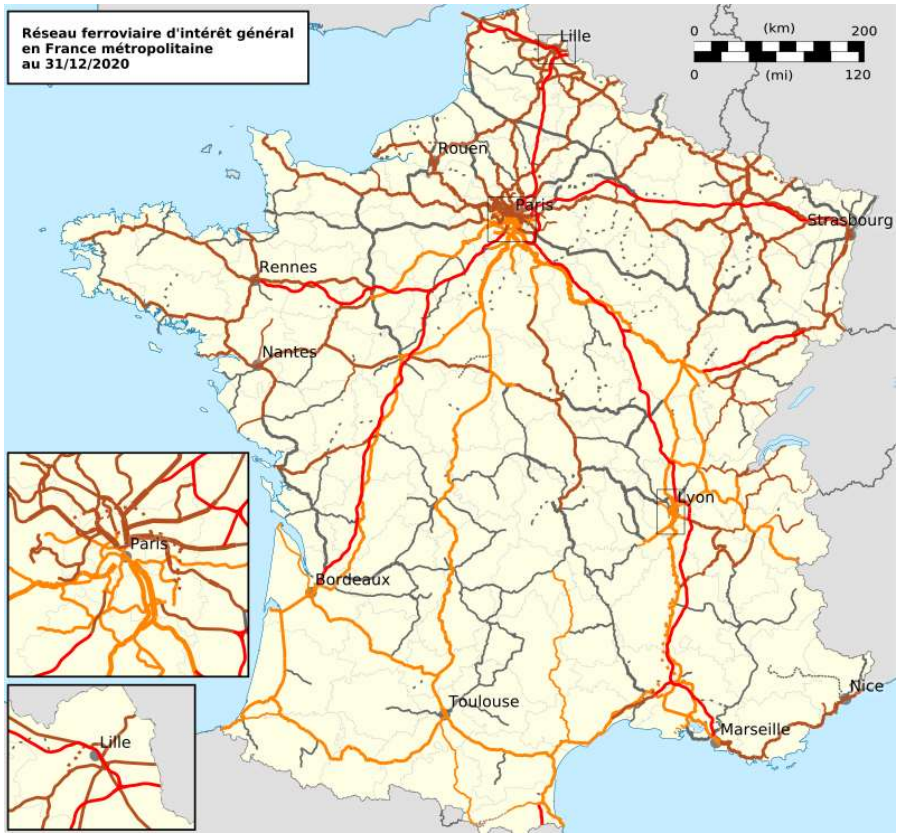
# Road Networks

- Highly redundant
- Self- organized
- Very transparent
- Example: Blocking of almost all major north-south connections in the German federal highway network
  - Only 4% increase in overall travel time
  - Initial chaos has to be overcome




Infrastructure: not the critical resource



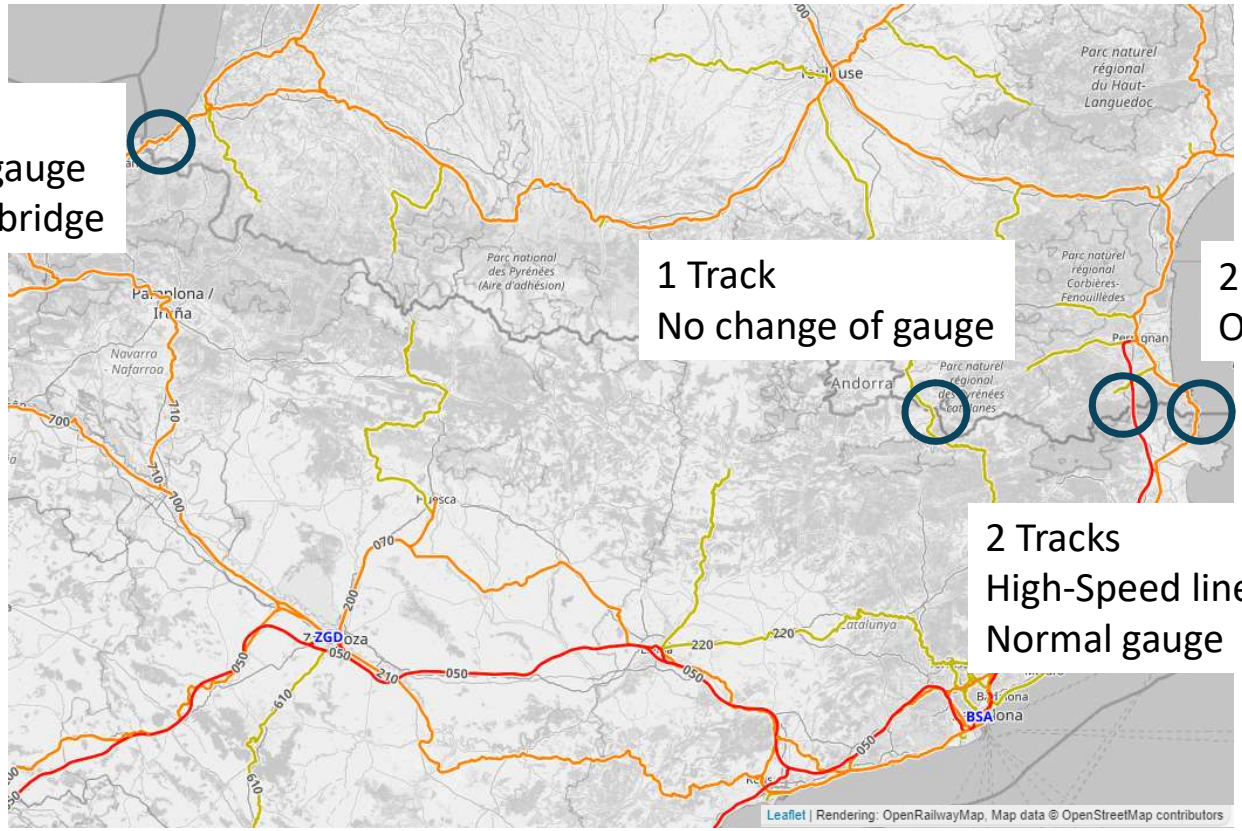

Par Le dessin des frontières, des côtes et de l'hydrographie utilise des données issues des bases Geofla 2016 et EGM 2020, publiées par l'Institut géographique national sous la licence Licence ouverte / Open license d'Etalab. — Travail personnel, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=98895403

# Railways

- Critical links: natural barriers (mountain chains)
- Capped lines
- Disregard of freight in high-speed projects
- Train control/tension/frequency…. Still an issue?

# Railways

2 Tracks
One for each gauge
Use the same bridge

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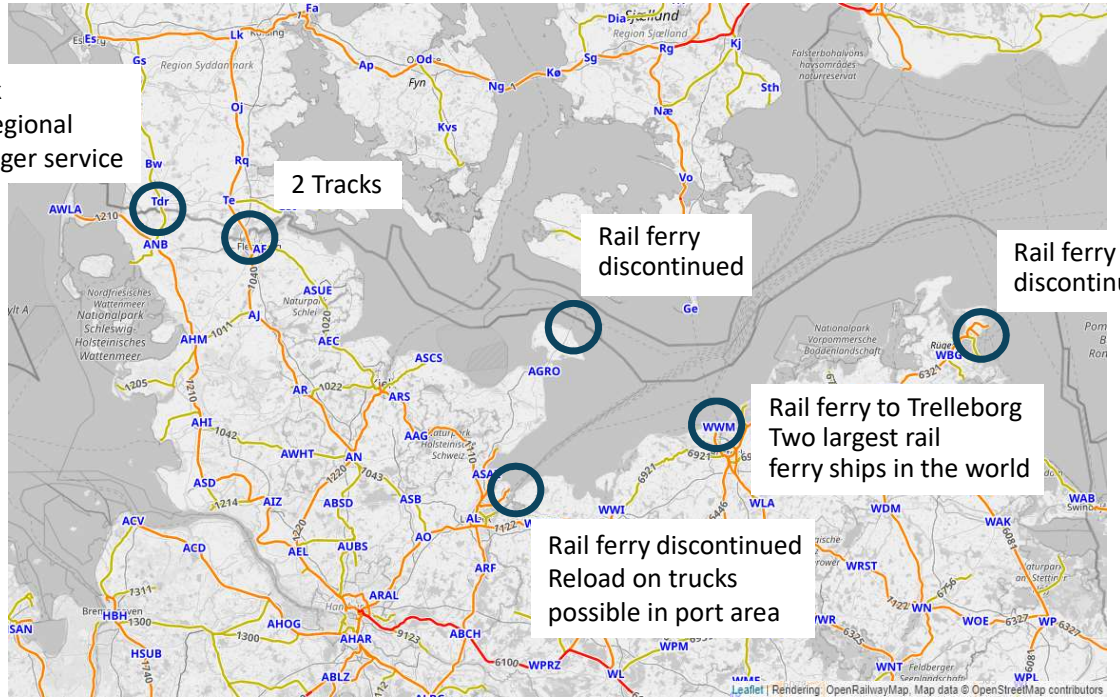
# Railways

Need of the road system as a backup

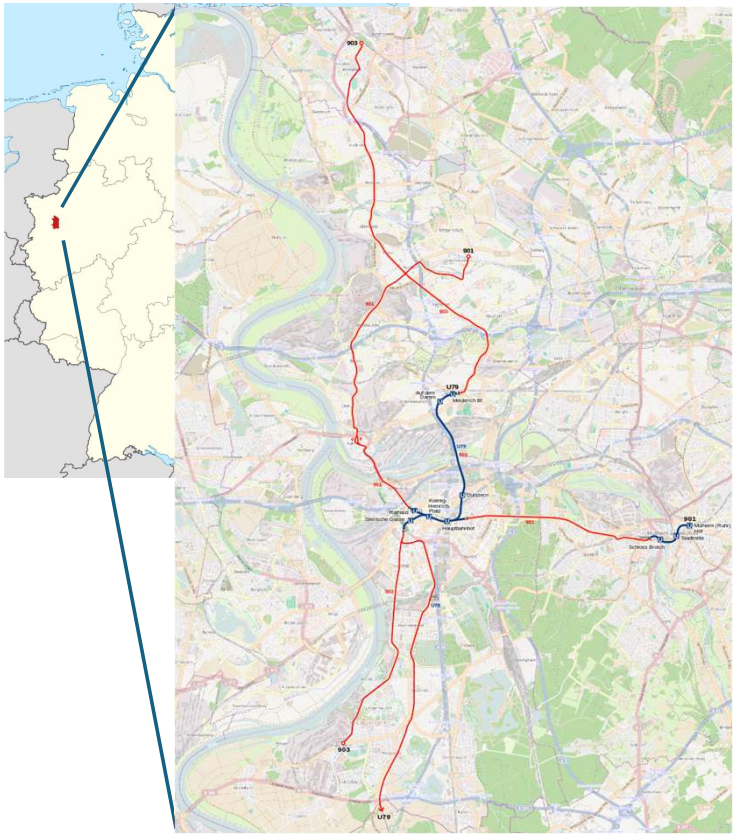


# Public transport networks

- Robustness and resilience depend on
  - Infrastructure design
  - Design of lines on the infrastructure networks
- Examples: Public transport networks in Duisburg and Dresden

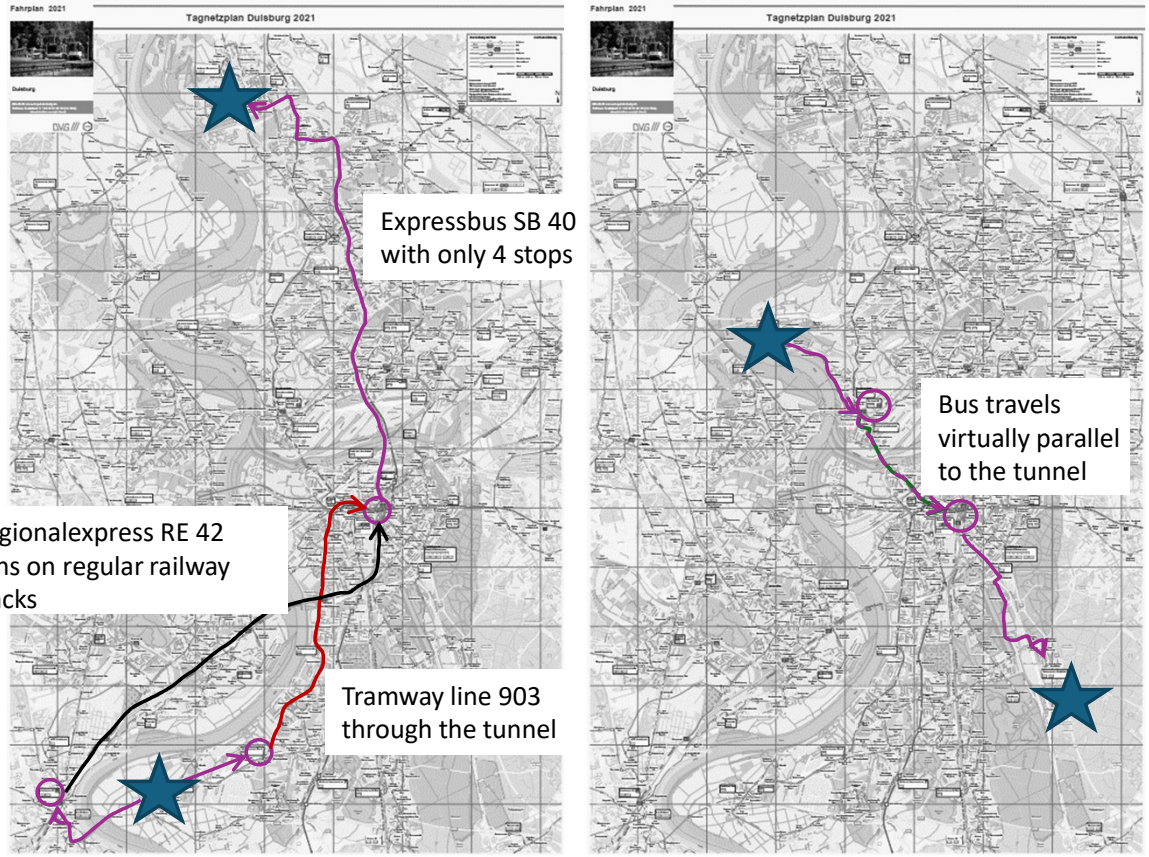
# Public transport networks

- **Example Duisburg**
- Public transport concentrated on two tramway lines and a light rail line
- All lines share a tunnel (partly two-story)
- Many routes are linked over these lines
- Only few cross-connections



# Public transport networks

- Itineraries that avoid the tunnel are possible
- They have a lower capacity
- Parallel lines instead of cross-connections

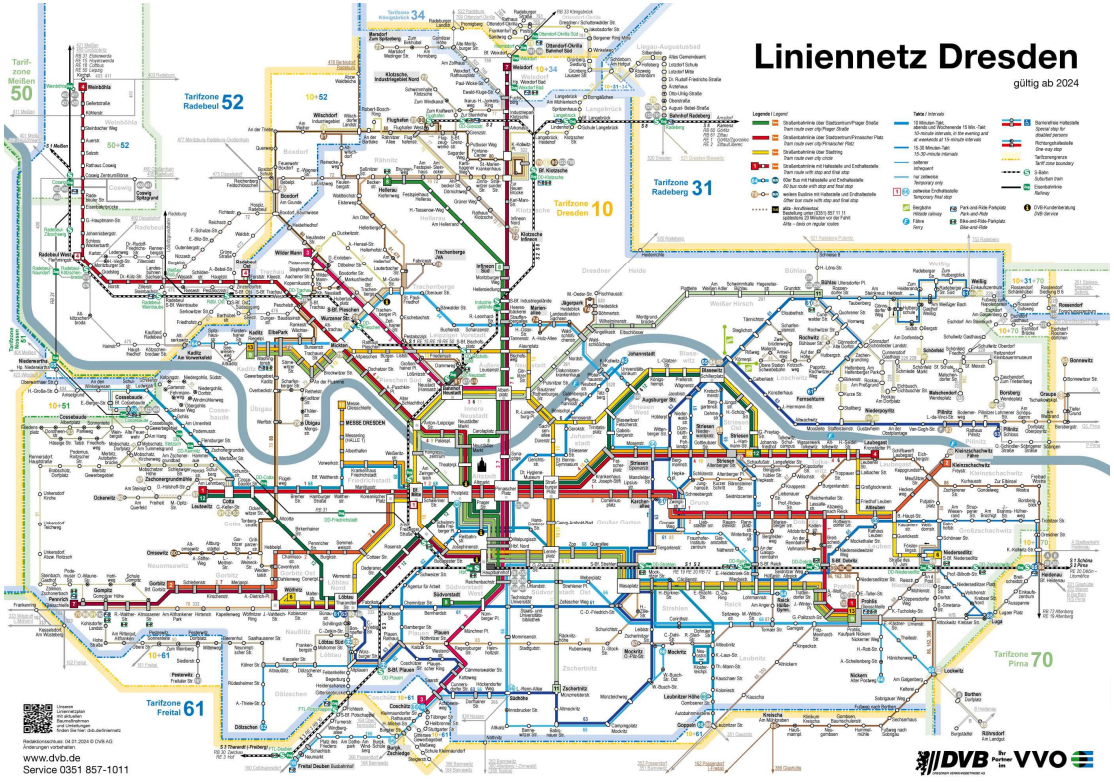



dvg-duisburg.de/fileadmin/Media/Downloads/Linienplaene/Liniennetzplan/DVG_Liniennetzplan_Tag.pdf

# Public transport networks

- **Example Dresden**
- Based on area-covering tram network
- Supplemented by bus lines and suburban trains on the regular rail network

Spatial and mode diversity increase quality: every day and in cases of disruptions




https://www.dvb.de/-/media/files/liniennetz/dvb_lnp_010124_standard_pdf.pdf

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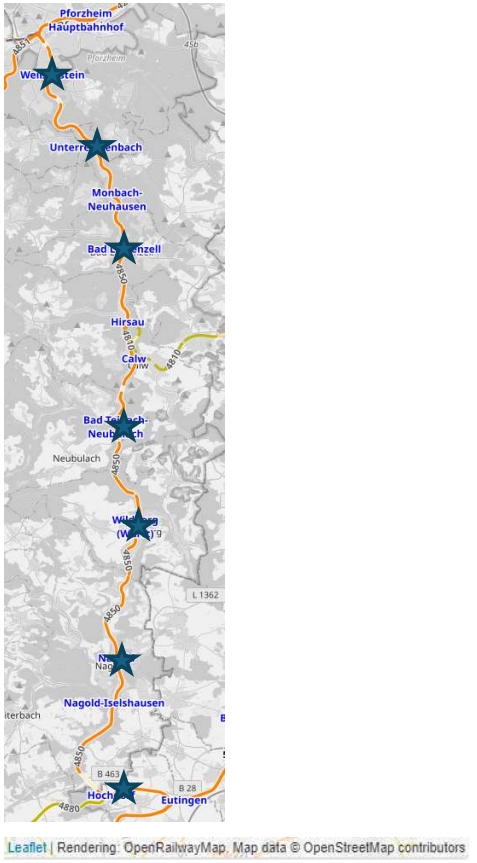
# Public transport networks

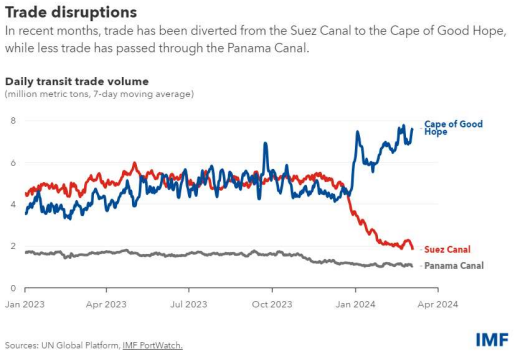
- Example: Single track line in the northern black forest
- Maximum travel time between passing sidings ~15 Min
- With timetable cycle of one hour:
  - Trains have normally only to wait in every second station
  - Delay per train: 3 min or 15 or 30 min
  - Delay needs to be accounted for at the terminus

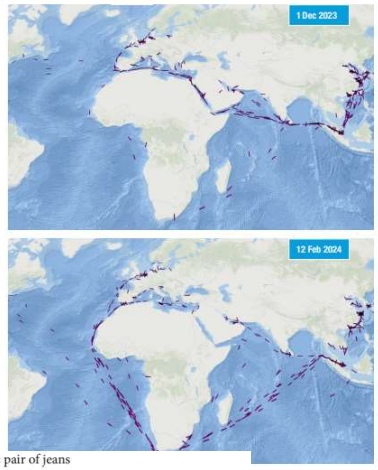
Stable against small delays 0…4 min
Stability not given against mid-size delays

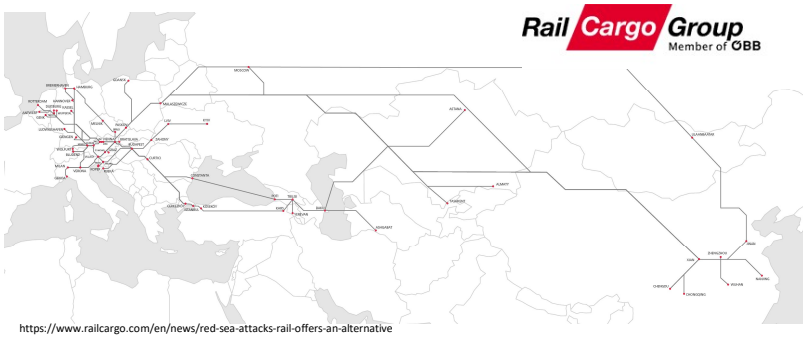


# World wide waterways and logistics

- Suez and Panama canal

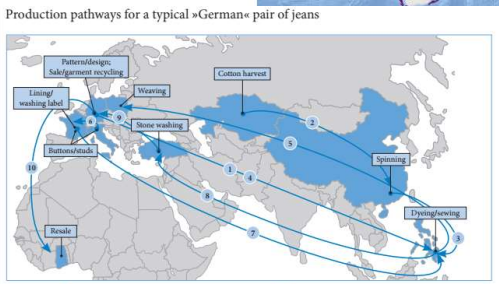



https://www.railcargo.com/en/news/red-sea-attacks-rail-offers-an-alternative

- Security paradox




Roth et. al. (2015)

# World wide waterways and logistics

- Companies already reacted to transport problems
  - Stocks are going to increase
  - Other ways or modes of transport are considered

## Shallow Water, No Problem: HGK Orders Gas Tanker with "Special Dimensions"

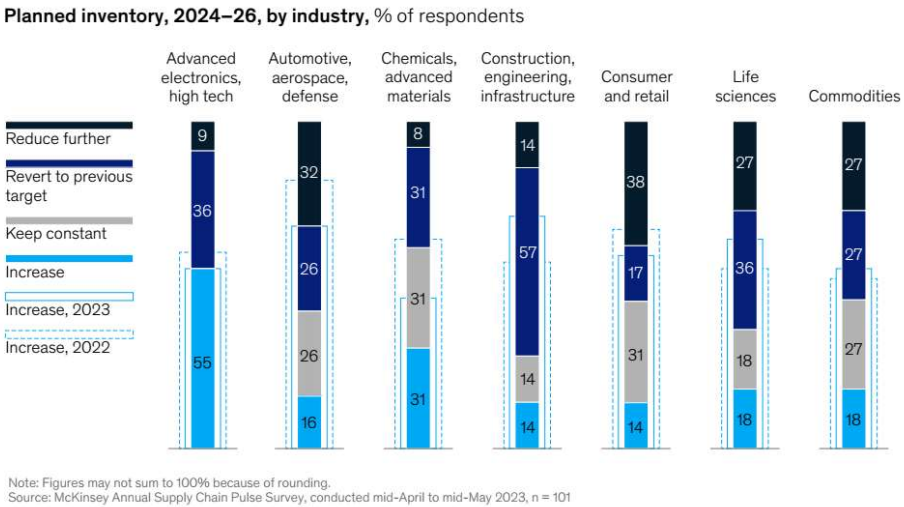
September 18, 2023

Technical drawing: a 3D ship's drawing of the 'GAS 96'.
Source: HGK Shipping

***Optimized to deal with shallow water levels, a diesel-electric drive system and an extra-wide design for the vessel are the main features of a gas tanker that HGK Shipping ordered from the Dutch shipyard, De Gerlien Van Tiem, on September 15, 2023.***

The latest addition to the fleet will enable the Duisburg, Germany inland shipping company to maximize cargo carriage even if water levels are low. **"GAS 96"** has been developed in close cooperation in line with the requirements

https://www.marinelink.com/news/shallow-water-problem-hgk-orders-gas-508120



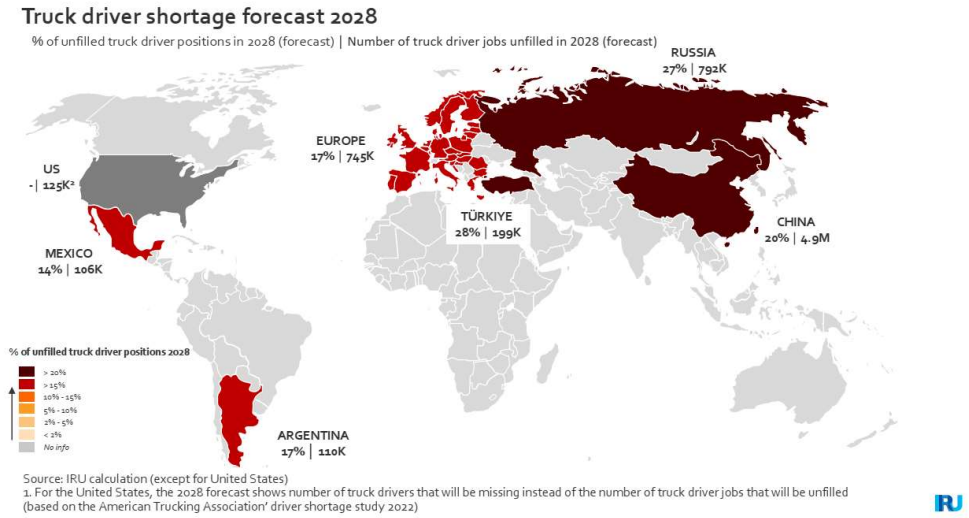

Note: Figures may not sum to 100% because of rounding.
Source: McKinsey Annual Supply Chain Pulse Survey, conducted mid-April to mid-May 2023, n = 101

- The big events have (finally) achieved a rethink in inventory policy and supply chain diversification

# World wide waterways and logistics

- Systemic view is needed
  - Quick changes of mode and/or way are not feasible in larger scales
  - Infrastructure is not the only bottleneck
    - Rolling stock
    - Drivers

The private sector has to contribute to resilience





Commodities

**Germany to give energy essentials priority by rail if Rhine disruption worsens**

By **Reuters**

August 14, 2022 3:07 PM GMT+2 · Updated 2 years ago

https://www.reuters.com/markets/commodities/germany-give-energy-essentials-priority-by-rail-if-rhine-disruption-worsens-2022-08-14/

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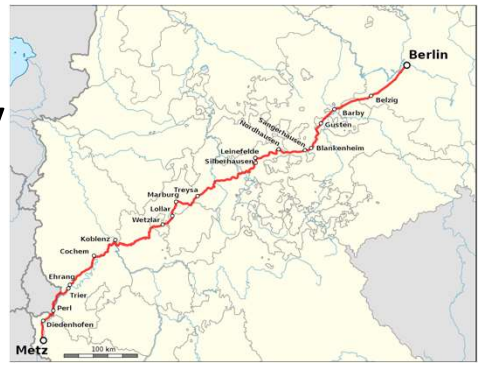
- **Special purpose infrastructures?**
- **Network topology measures?**
- **Summary**

# Rationale of special purpose infrastructures

- Something that is not really needed now is built
- Large infrastructure projects of economic or military importance
  - Always came too late
  - Have a maintenance cost problem
- Threads are always different than anticipated
  - They are quick and infrastructure expansion is slow

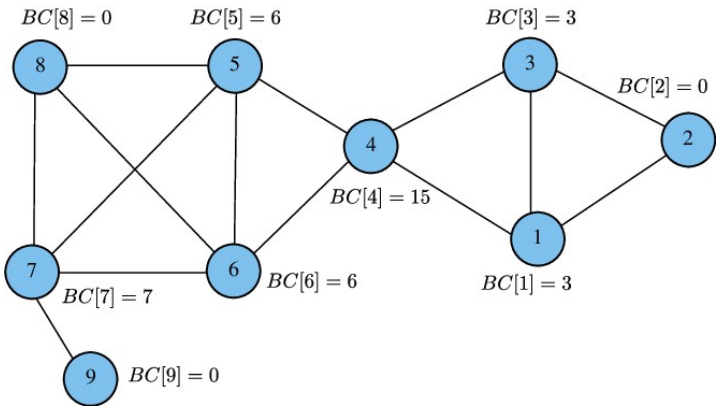




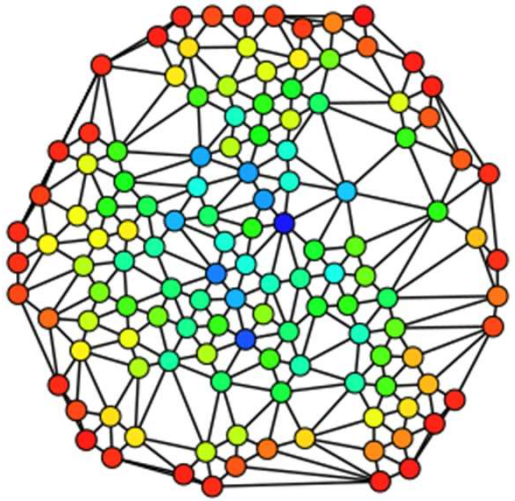



It does often make no sense to build infrastructures against a particular challenge…

# Network topology measures




Scalable and High Performance Betweenness Centrality on the GPU - Scientific Figure on ResearchGate.
Available from: https://www.researchgate.net/figure/Example-Betweenness-Centrality-scores-for-a-small-graph_fig1_282990849



By Claudio Rocchini - Own work, CC BY 2.5,
https://commons.wikimedia.org/w/index.php?curid=1988980

- Critical Element: Significant additional cost, if missing
- Critical Element – High traffic volume, difficult to evade

- Critical Network state: small fluctuations in operations tend to increase!

# Summary

- Resilience and over-capacity are linked
- Over-capacity in infrastructure and other resources (vehicles) needed
- Over-capacities can have other benefits: accessibility
- Trancparency and interoperability increase resilience

- Implications for planning
  - Resilience is not only a task for planning
  - Governance and sector organisation (contracting transport services)
  - Cross-network standardisation for backup operations
  - Each notwork should conduct stress-tests

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