## Design case studies A: Electric vans and Docklands Light Railway

Engr 514:2014 Design of safety-critical systems Roger Kemp, January 2014

#### **Historic EV**



# The project – to move EVs from a "tree-huggers' car" to a commercial vehicle





## Lead-acid traction battery



### Key parameters

- 6 V
- 180 Ah
- 32 kg
- ~ 34 Wh/kg

$$PbO_2 + SO_4^{2-} + 4H^+ + 2e^- \longrightarrow PbSO_4 + 2H_2O$$

## Types of secondary battery

	Wh/kg	W/kg	Cycle life	€/kWh
Lead-acid	35	200	600-1000	150
Nickel-cadmium	50	175	1500 - 2000	600
Nickel-metal hydride	70	200	1500 ?	250 ?
Sodium-sulphur	150	200	600 ?	250 ?
Sodium-nickel chloride	90	110	1000 ?	250 ?
Zinc-bromine	70	100	1000 ?	250 ?
Zinc-air	180	125	400 ?	125 ?
Lithium	200 ?	400 ?	1000 ?	100 ?

Look at: <a href="http://www.powerstream.com">http://www.powerstream.com</a>

## **Installing batteries**



Low energy density (compared with petrol)



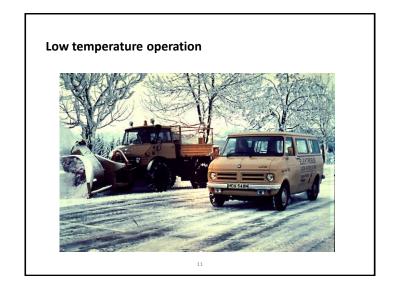
Safety risks in the EV programme

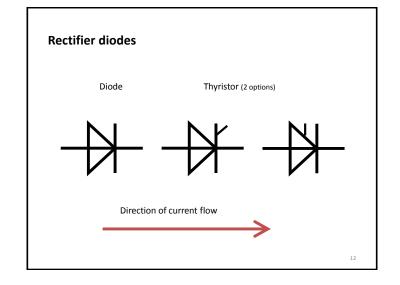
Hazard	Risk level
Fault in structure of van, steering, etc.	UNLIKELY
Fault in control system, resulting in runaway	MODERATE
Explosion caused by battery (and/or hydrogen)	MODERATE
Electrocution of maintenance or servicing personnel	POSSIBLE
Leaking acid caused by accident	MODERATE
Fire caused by short-circuit battery	MODERATE
etc.	

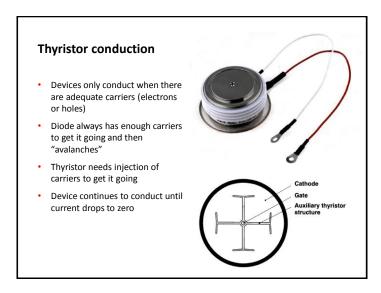
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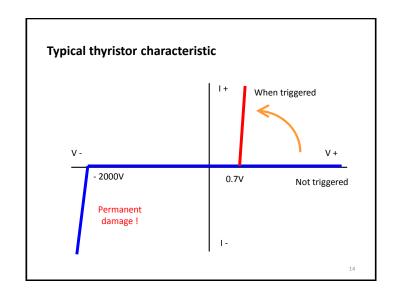


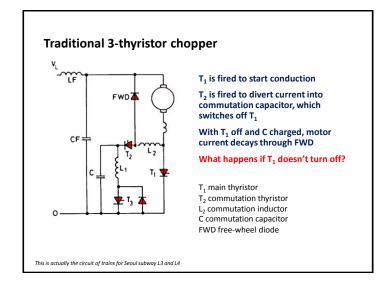


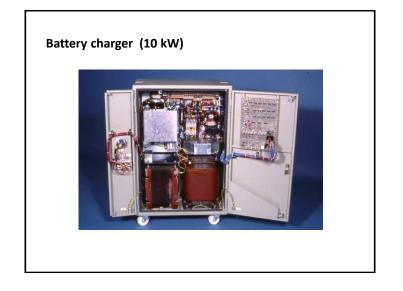












## Failure of battery ventilation



- Hydrogen generated by charging process
- Insufficient ventilation to dissipate the gas
- Explosive mixture ignited by spark

This raised battery ventilation to the status of a safety-critical system

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## **Explosion test**



## **Evening News fire**



This raised charger management to the status of a safety-critical system

- Battery charger "on" all long weekend
- Plates distorted
- Short circuit leading to thermal runaway
- Battery discharged very quickly
- Molten lead formed pool under vehicle

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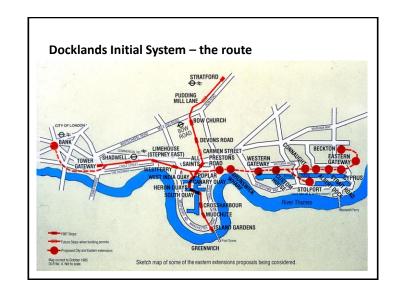
## The problem – economics



- What constitutes suitable EV operation?
  - $\frac{Daily\ mileage}{Maximum\ range} \approx 1$
- No safety issues prevented introduction of electric vans

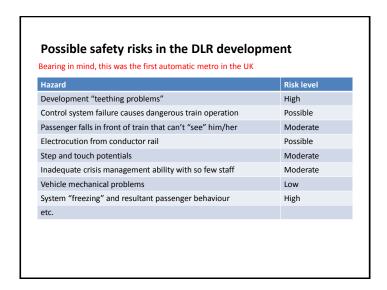


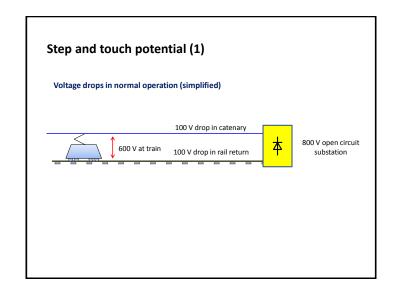


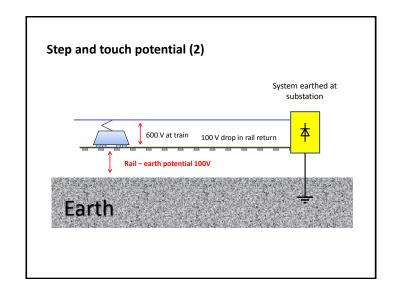


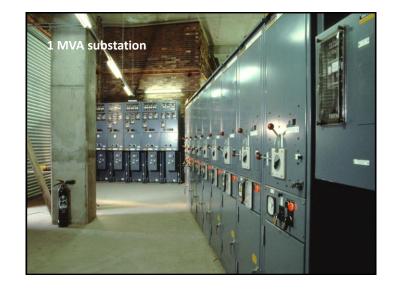


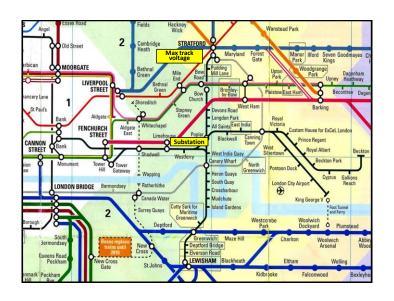


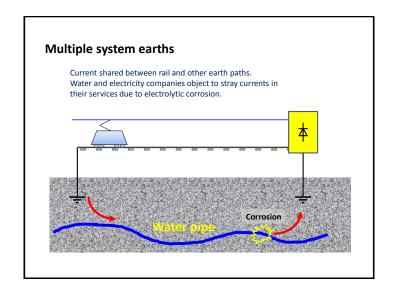


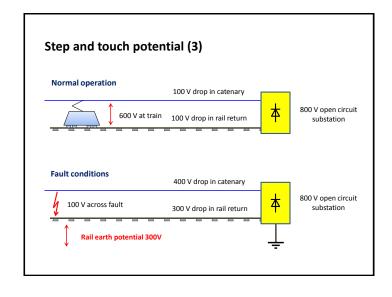


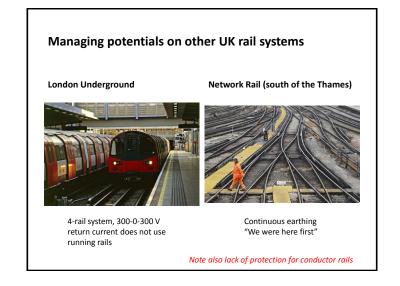












# Other metro system practice

#### Atlanta

#### San Francisco





Both these systems use a third rail with good insulation between rail and earth and ensure that passengers cannot touch "real earth" at the same time as a train.

## Insulating the trackbed

Re-bar at N Quay junction

Testing effect of re-bar design on transmission of train control signals





Longitudinal re-bars connected back to substation via earthing cable and "drainage diode"

#### **Stratford station**



- No earthed metalwork (including vending machines) within reach of platform edge
- Insulating layer below paved surface

## Protecting the 3<sup>rd</sup> rail (discovering best practice?)







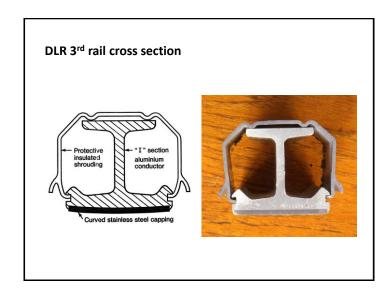
Detroit people-mover



Chicago people-mover



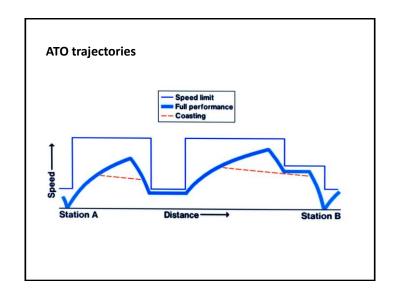
Lyon Line D

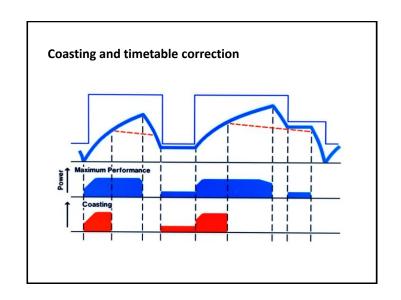




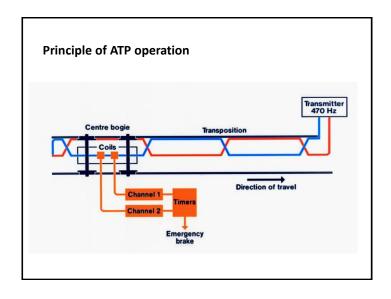
## **DLR – Automatic control systems**

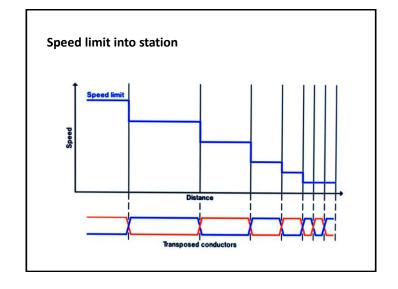
- Constraints
  - Client requirement for no drivers
  - 3 years from contract to passenger operation
- Decision to separate ATO and ATP systems, rather than design a SIL4 ATO
  - Automatic train operation (ATO) can be SILO
  - Automatic train protection (ATP) must be SIL4

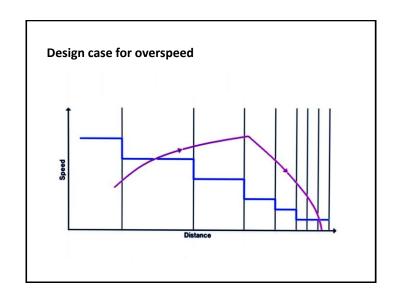


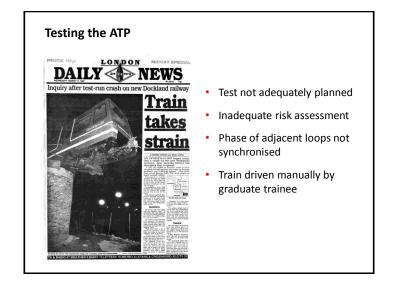






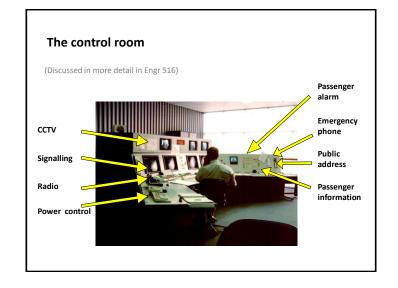






## Requirements for control room operation

- One person operation
  - with assistant at busy times
- Signs-on train captains
  - allocates duties and radios
- Manually controls trains from depot to system
- Manages possessions
- Responds to passenger alarms, observes CCTV
- Supervises automatic systems



#### **HMRI** criticisms

- Low refresh rate of screens so controller did not know what was happening
- Highly variable workload resulting in controller overload
- Too many controller distractions

   e.g. signing-on train crew, possessions,
   passenger queries, radio to train crew, ...
- Poor alarm rationalisation
- No planned emergency actions





## Redesigned interface

(Discussed in more detail in Engr 516)



## **Manual driving**



- Used when there is an equipment fault
- Train manager can override automatic systems
- No trackside signals
- Permission to proceed given over radio link

The only accident in passenger service was caused by the controller giving permission for a train to proceed over a junction without cancelling automatic operation on all conflicting routes.

#### Main issues

- Project safety must consider all hazards not just those that are easy to analyse or that correspond to a team's competences or preconceptions.
- Safety management must be embedded in the project structure – not seen as a separate deliverable managed by a remote team
- Imagination to ensure all hazards are covered is more important than the detail of how each is analysed.