C4R

Capacity for Rail

SP4 Advanced Monitoring

Paris – 15/03/2017

Edd Stewart, The University of Birmingham
WP4.2 Leader

UNIVERSITY OF BIRMINGHAM

SEVENTH FRAMEWORK PROGRAMME

Overview

- Introduction to SP4
- Technology evaluation frameworks
- Selected technologies for field testing
- Field testing/ demonstration activities

Capacity for Rail

Introduction to SP4

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SEVENTH FRAMEWORK PROGRAMME

SP4

The development of innovative monitoring systems for the rail industry

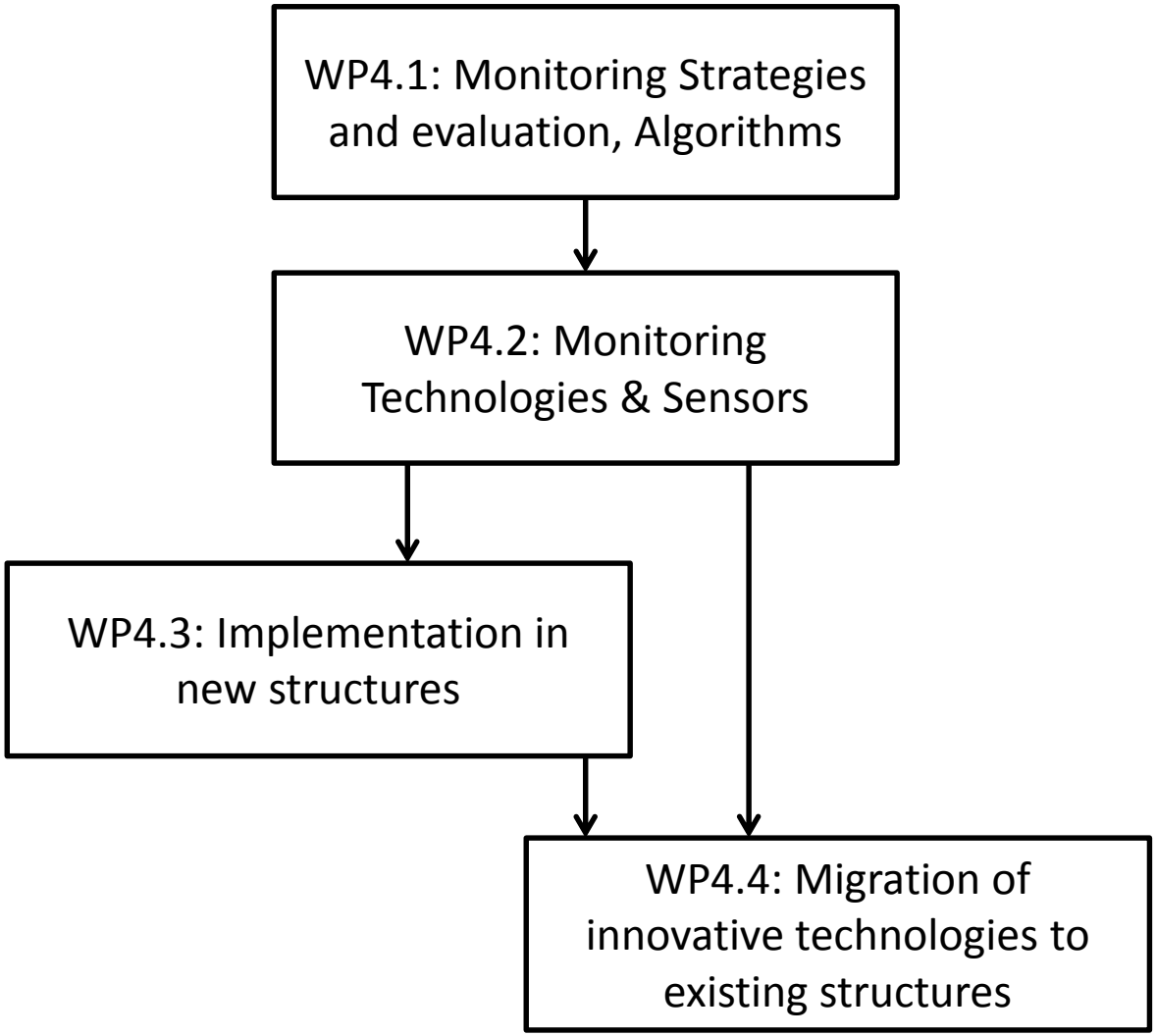
WP4.1 - Monitoring Strategies
- Identify key components / systems
- Identify monitoring possibilities
- Identify deterioration parameters and methods for prediction
- Identify data collection strategies

WP4.2 - Monitoring Technologies
- Identification and evaluation of key technologies:
  - Sensing
  - Energy harvesting
  - Communications
  - Data / processing

WP4.3 - Implementation in new structures
- Review of new track structures for weak points and risk levels
- Develop built-in monitoring systems
- Processes for operation and maintenance

WP4.4 - Migration of innovative technologies to existing structures
- Development of retro-fit monitoring systems
- Integration with existing maintenance processes

SP4


WP4.1: Monitoring Strategies and evaluation, Algorithms
WP4.2: Monitoring Technologies & Sensors
WP4.3: Implementation in new structures
WP4.4: Migration of innovative technologies to existing structures

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Capacity for Rail

Technology Evaluation Frameworks

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Technology Evaluation

Technologies to be used to develop integrated solutions for next generation railway monitoring and inspection

- Specification, identification and evaluation

Scope

- Sensing, energy harvesting, communications, processing and data integration

Expectations

- Low cost, robust, intelligent, and low power

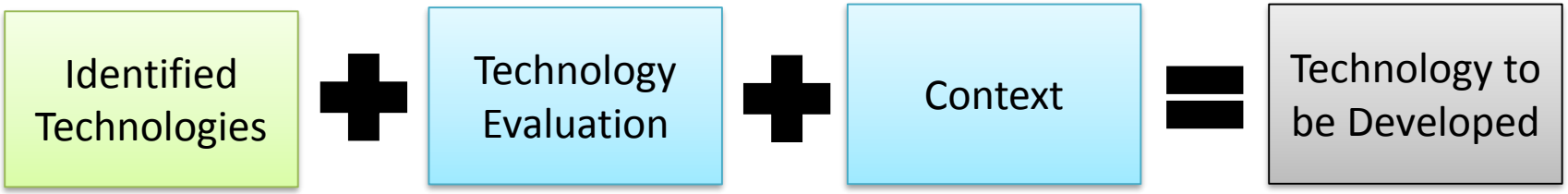
Near-horizon technologies or technology transfer from other domains

- Not the development of entirely new approaches

Technology Evaluation

- Identify key requirements for inspection and monitoring systems
  - Measure what you need, not what you can…
- Review technology use in rail and other industries
- Select appropriate sensing technologies and processing for low energy systems
- Select appropriate communications technologies
- Identify appropriate data formats and communications strategies
- Development of demonstration case studies

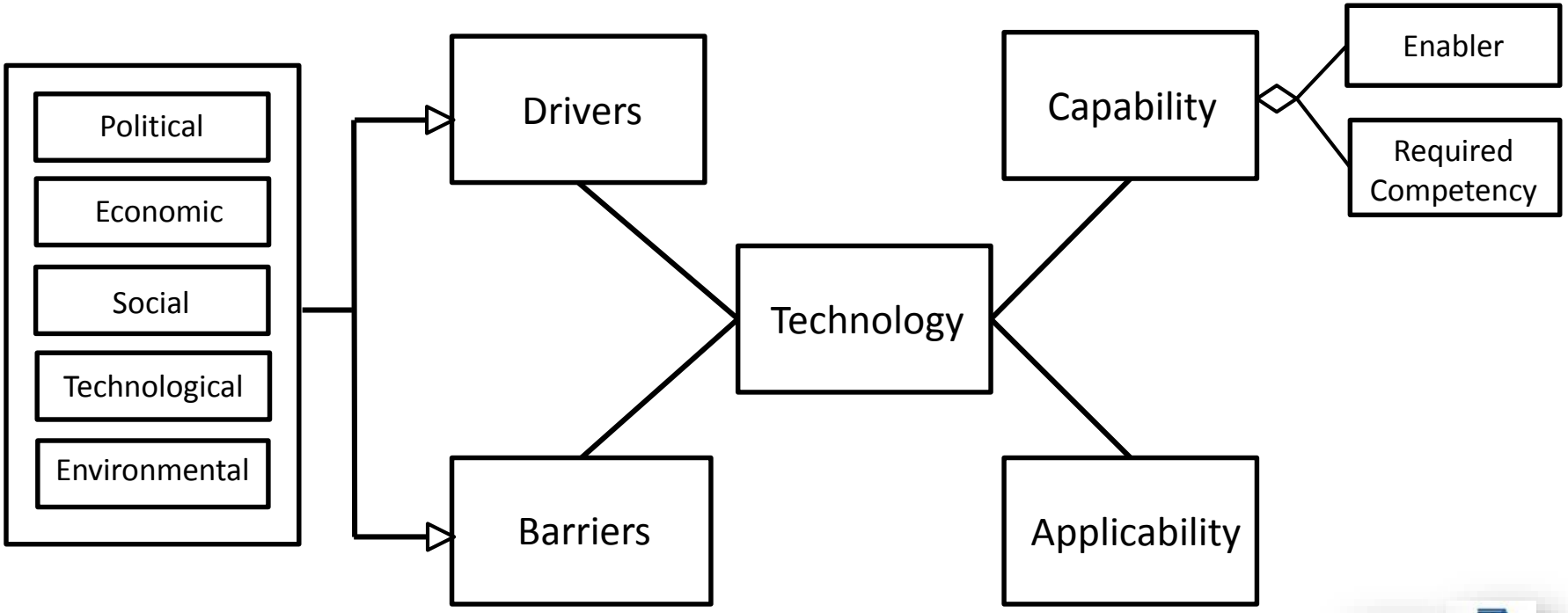
Technology Evaluation



Technology Identification Framework

Technology Market Place

Which technologies could be developed given the Market Place?
What is missing in the Market Place to progress the technologies?



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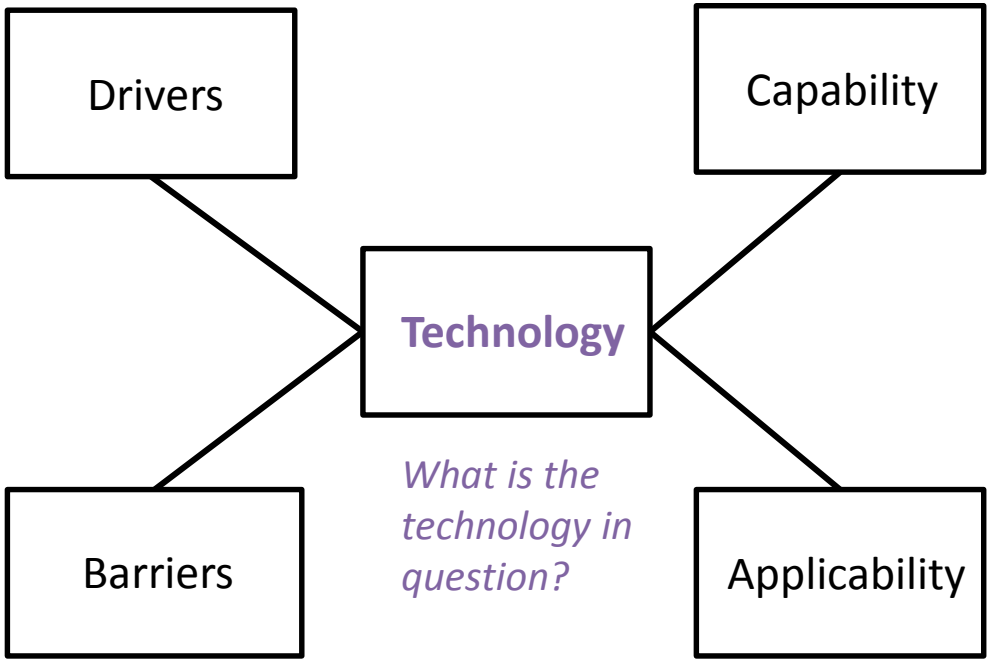

Technology Identification Framework

Capacity for Rail

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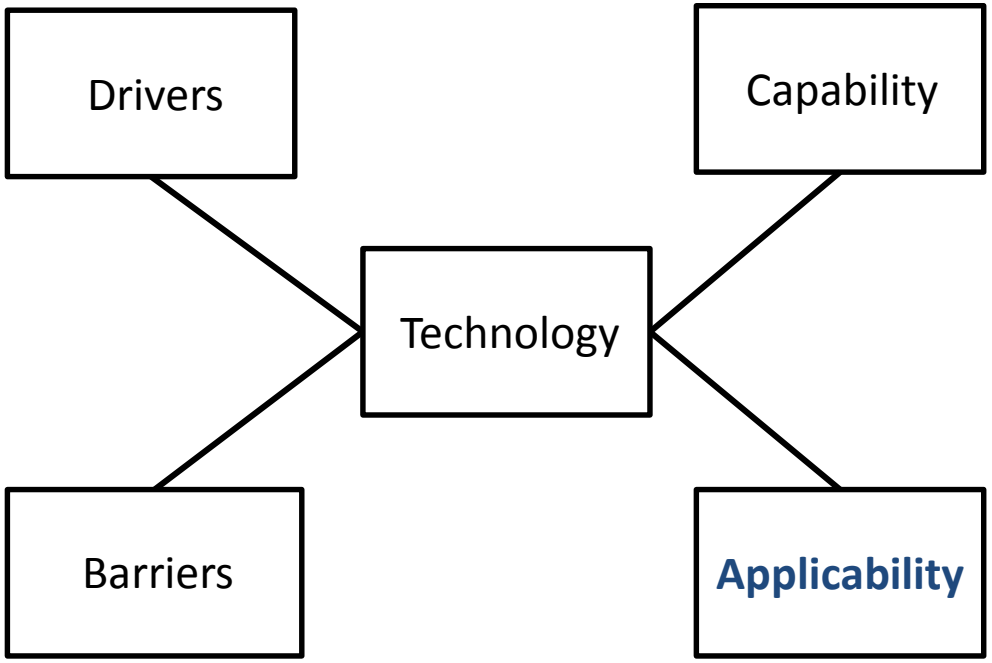


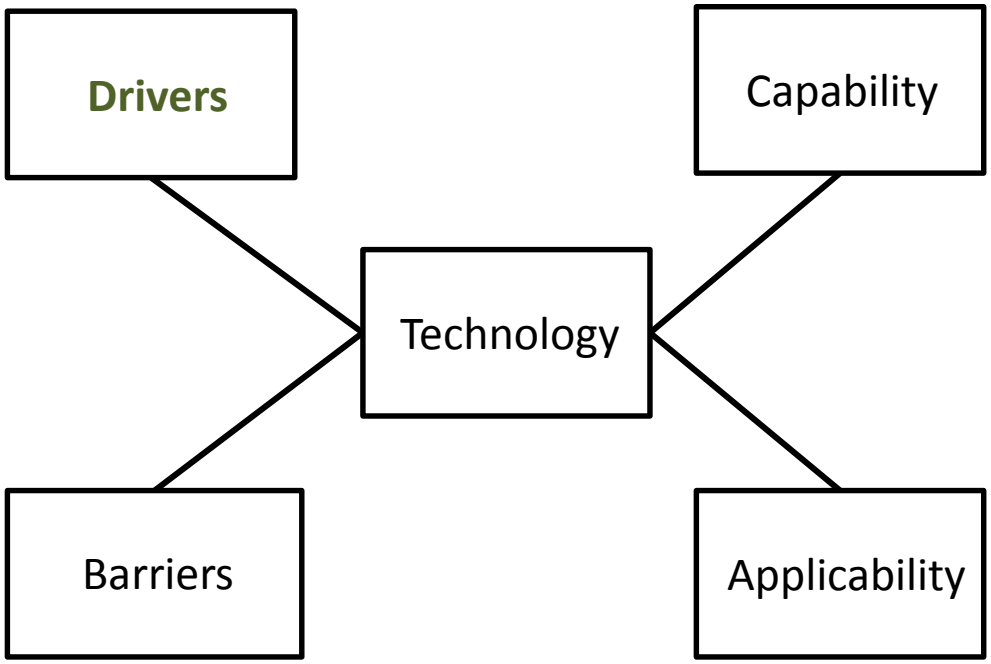
Where could the Technology be applied?

Technology Identification Framework

Technology Market Place

Which technologies could be developed given the Market Place?
What is missing in the Market Place to progress the technologies?

Where are the drivers for introducing the Technology?



Technology Identification Framework

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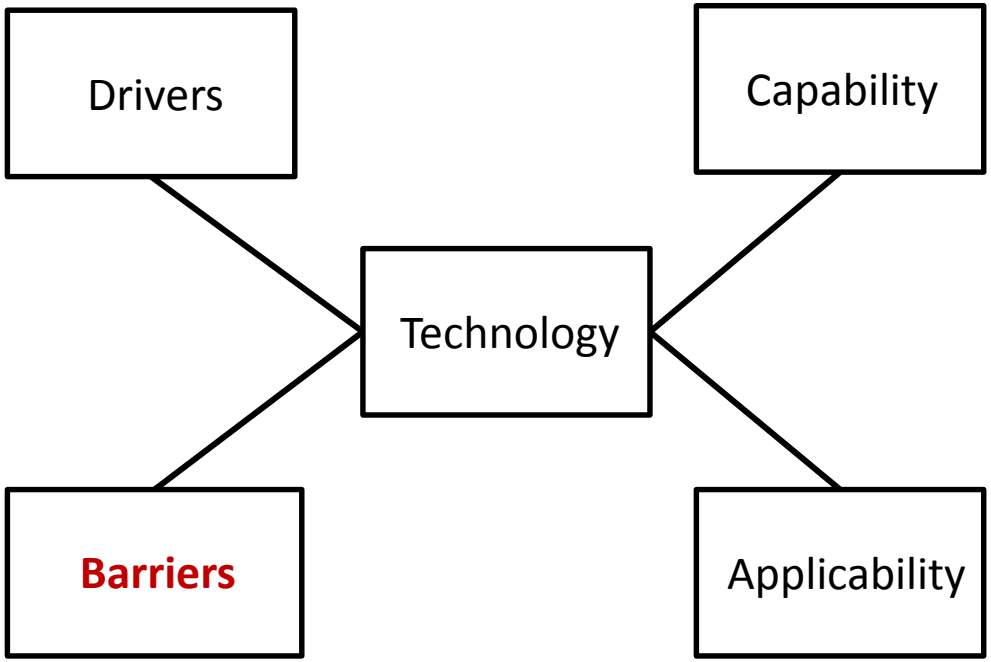

Where are the barriers to introducing the Technology?

Technology Identification Framework

Technology Market Place

Which technologies could be developed given the Market Place?
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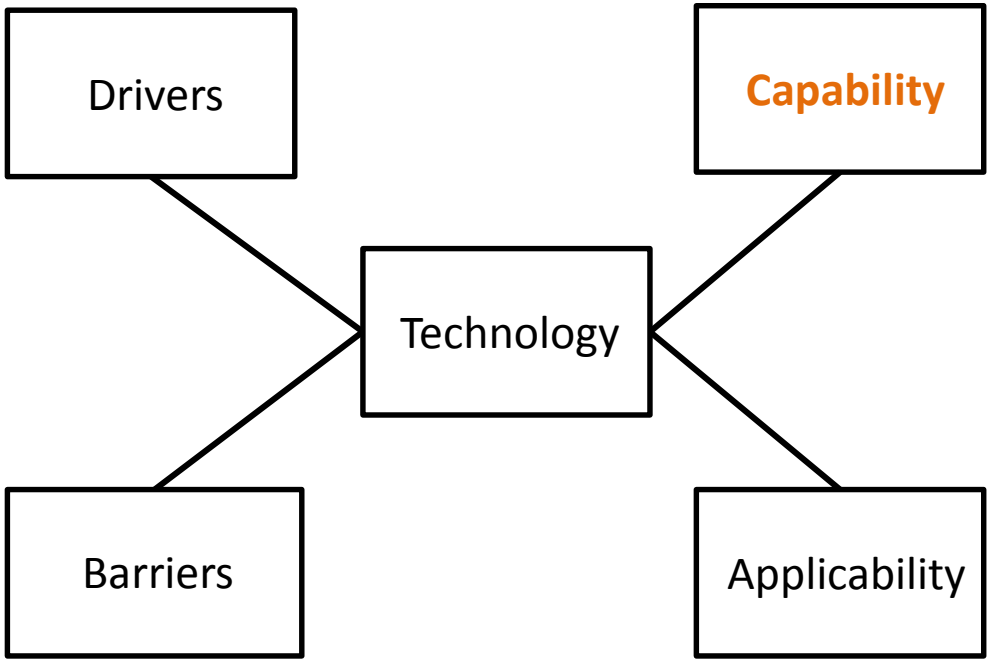
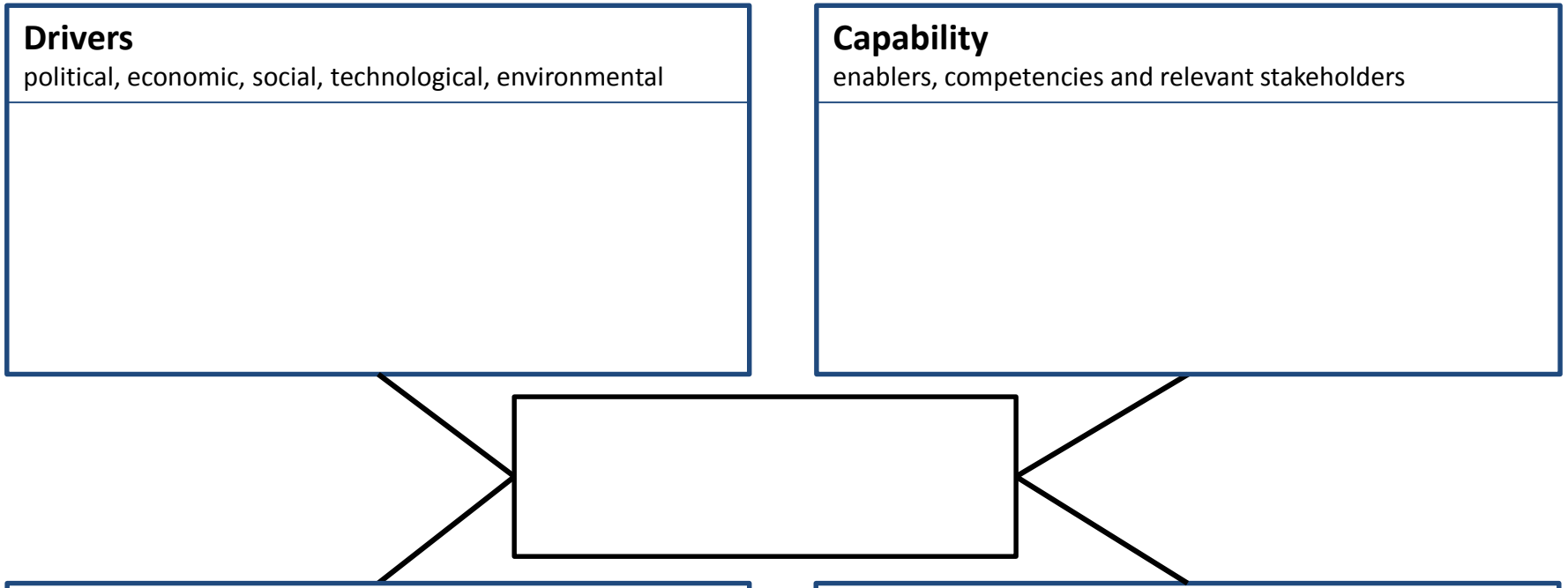


What capability is required to realise the Technology?

Technology Identification Framework



Technology Identification Framework

Drivers
political, economic, social, technological, environmental

Effective proven technology
Non-invasive
Existing safety cases

Capability
enablers, competencies and relevant stakeholders

IR cameras
IR specialist
Threshold based processing
Graphics co-processing
Calibration

Infrared Imaging

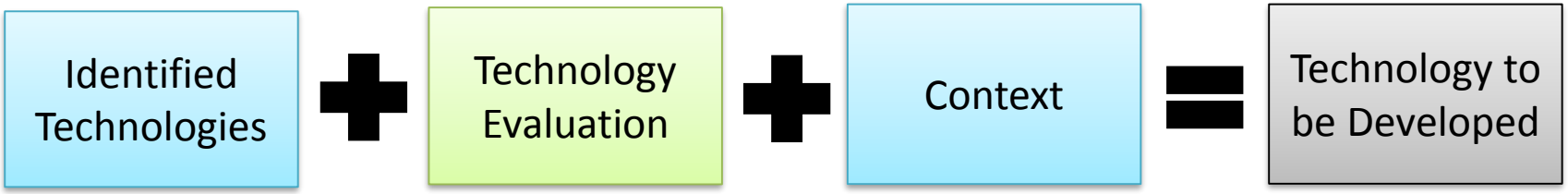
Barriers
political, economic, social, technological, environmental

Technically limited (resolution + speed)
Last-minute detection (mechanical)
Weather sensitive
Sensitive to emissivity
Potential damage to lenses from dirt

Applicability
application, stakeholders, business case and business model

Hot spots
Electrical
Mechanical
Vegetation

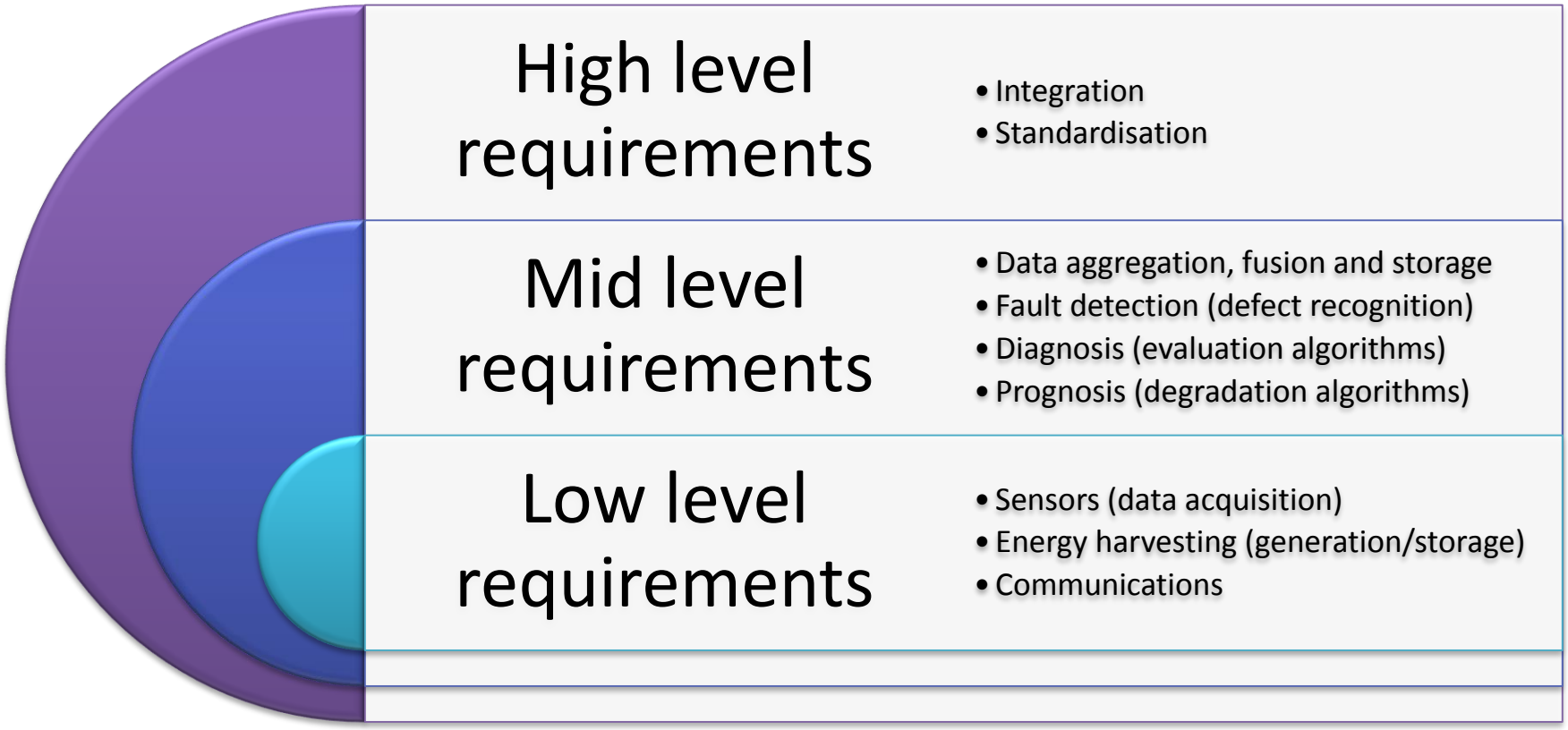
Technology Evaluation



Technology Evaluation Framework

Capacity for Rail

Evaluation at multiple levels



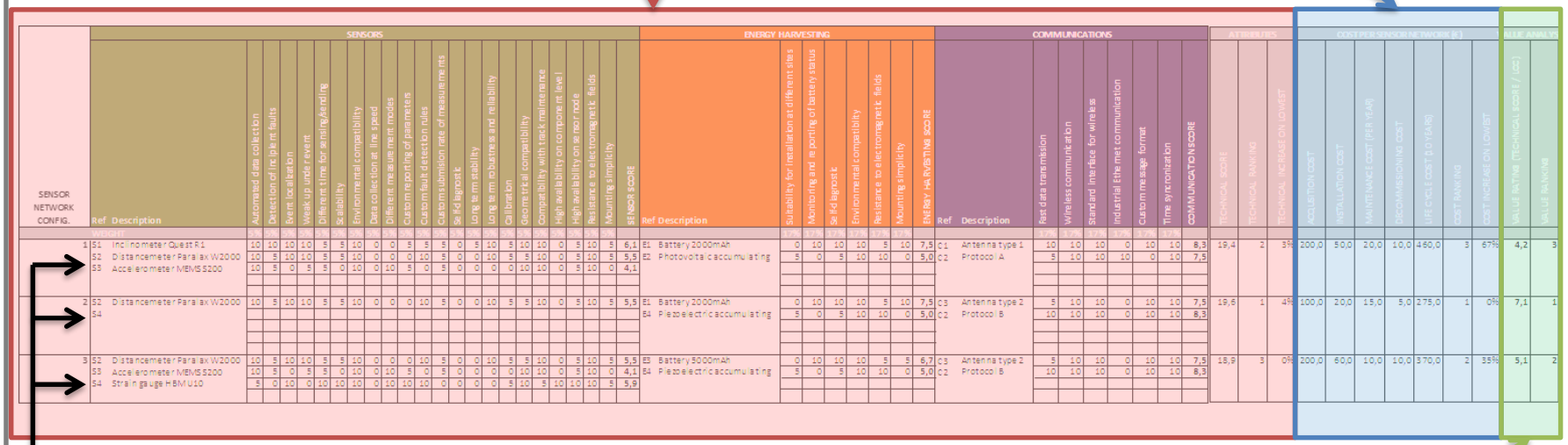
Technology Evaluation Framework

Capacity for Rail

Evaluation against: sensing, energy harvesting, communications, and cost

Technical Evaluation

Cost Evaluation



SENSOR NETWORK CONFIG.		SENSORS																																ENERGY HARVESTING								COMMUNICATIONS										ATTRIBUTES			COST PER SENSOR NETWORK (€)							LIFE ANALYSIS	
	Ref	Description	Automated data collection	Detection of incipient faults	Event localization	Wake up under request	Different time for sensing/sending	Scalability	Environmental compatibility	Data collection at line speed	Different measurement modes	Custom reporting of parameters	Custom fault detection rules	Custom submission rate of measurements	Self diagnostic	Long term stability	Long term robustness and reliability	Calibration	Geometrical compatibility	Compatibility with track maintenance	High availability on component level	High availability on sensor node	Resistance to electromagnetic fields	Mounting simplicity	SENSOR SCORE	Ref	Description	Suitability for installation at different sites	Monitoring and reporting of battery status	Self diagnostic	Environmental compatibility	Resistance to electromagnetic fields	Mounting simplicity	ENERGY HARVESTING SCORE	Ref	Description	Fast data transmission	Wireless communication	Standard interface for wireless	Industrial Ethernet communication	Custom message format	Time synchronization	COMMUNICATIONS SCORE	TECHNICAL SCORE	TECHNICAL RANKING	TECHNICAL INCREASE ON LOWEST	ACQUISITION COST	INSTALLATION COST	MAINTENANCE COST (PER YEAR)	DECOMMISSIONING COST	LIFE CYCLE COST (10 YEARS)	COST RANKING	COST INCREASE ON LOWEST	VALUE RATING (TECHNICAL SCORE / LCC)	VALUE RANKING
		WEIGHT	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%				17%	17%	17%	17%	17%	17%				17%	17%	17%	17%	17%	17%																				
1	S1	Inclinometer Questl R1	10	10	10	10	5	5	10	0	0	5	5	5	0	5	10	5	10	10	0	5	10	5	6,1	E1	Battery 2000mAh	0	10	10	10	5	10	7,5	C1	Antenna type 1	10	10	10	0	10	10	8,3	19,4	2	3%	200,0	50,0	20,0	10,0	460,0	3	67%	4,2	3
	S2	Distancemeter Parallax W2000	10	5	10	10	5	5	10	0	0	0	10	5	0	0	10	5	5	10	0	5	10	5	5,5	E2	Photovoltaic accumulating	5	0	5	10	10	0	5,0	C2	Protocol A	5	10	10	10	0	10	7,5																				
	S3	Accelerometer MEMS 5200	10	5	0	5	5	0	10	0	10	5	0	5	0	0	0	0	10	10	0	5	10	0	4,1																																									
2	S2	Distancemeter Parallax W2000	10	5	10	10	5	5	10	0	0	0	10	5	0	0	10	5	5	10	0	5	10	5	5,5	E1	Battery 2000mAh	0	10	10	10	5	10	7,5	C3	Antenna type 2	5	10	10	0	10	10	7,5	19,6	1	4%	100,0	20,0	15,0	5,0	275,0	1	0%	7,1	1
	S4																									E4	Piezoelectric accumulating	5	0	5	10	10	0	5,0	C2	Protocol B	10	10	10	0	10	10	8,3																				
3	S2	Distancemeter Parallax W2000	10	5	10	10	5	5	10	0	0	0	10	5	0	0	10	5	5	10	0	5	10	5	5,5	E3	Battery 5000mAh	0	10	10	10	5	5	6,7	C3	Antenna type 2	5	10	10	0	10	10	7,5	18,9	3	0%	200,0	60,0	10,0	10,0	370,0	2	39%	5,1	2
	S3	Accelerometer MEMS 5200	10	5	0	5	5	0	10	0	10	5	0	5	0	0	0	0	10	10	0	5	10	0	4,1	E4	Piezoelectric accumulating	5	0	5	10	10	0	5,0	C2	Protocol B	10	10	10	0	10	10	8,3																
	S4	Strain gauge HBM U10	5	0	10	0	10	10	10	0	10	10	10	0	0	0	0	5	10	5	10	10	10	5	5,9																																								

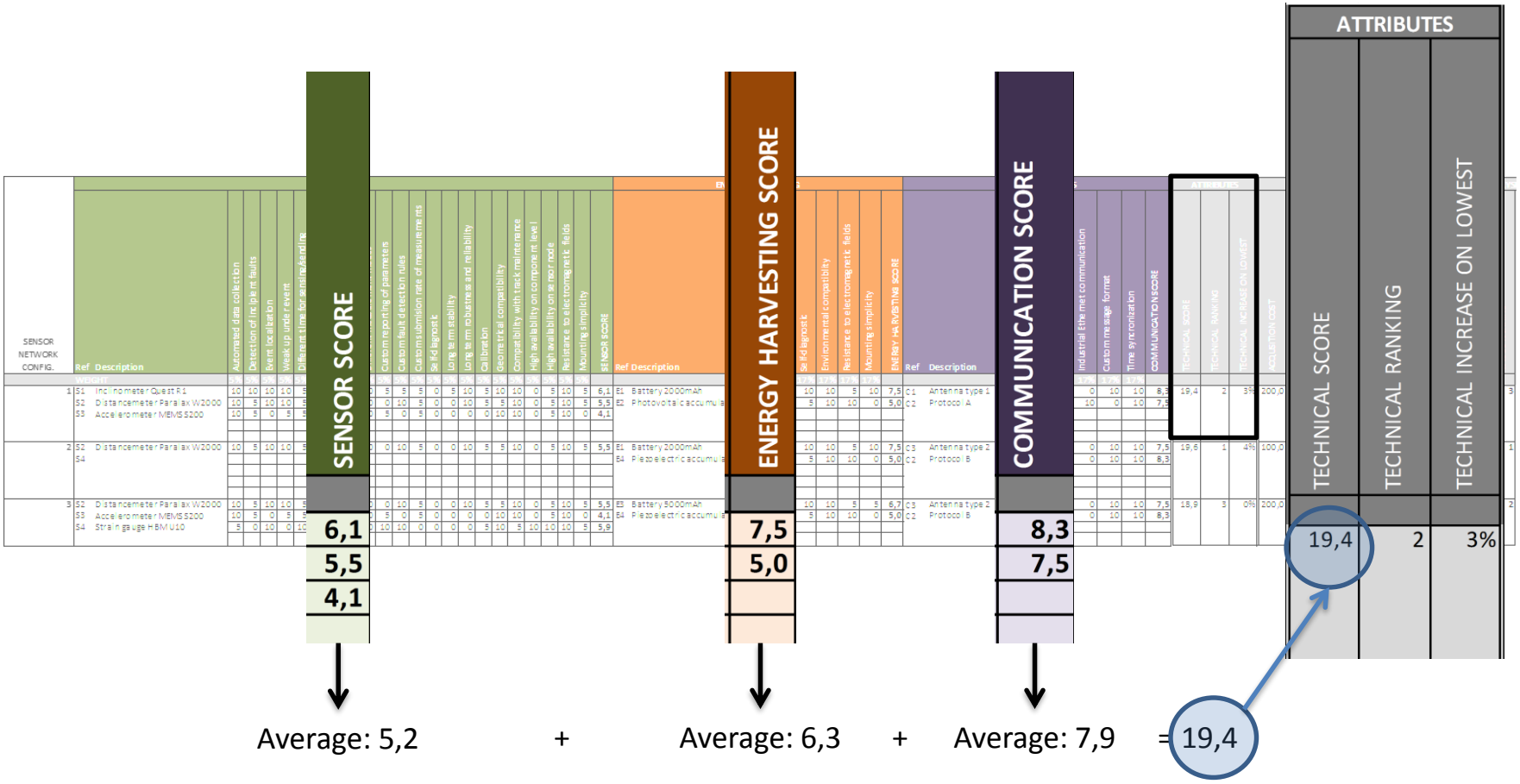
Comparison of different configurations

Value Analysis (Technical vs Cost)

Technology Evaluation Framework

Capacity for Rail

Scores in different requirement categories are collated



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Selected Technologies for Field Testing

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Sensor Evaluation / Comparison

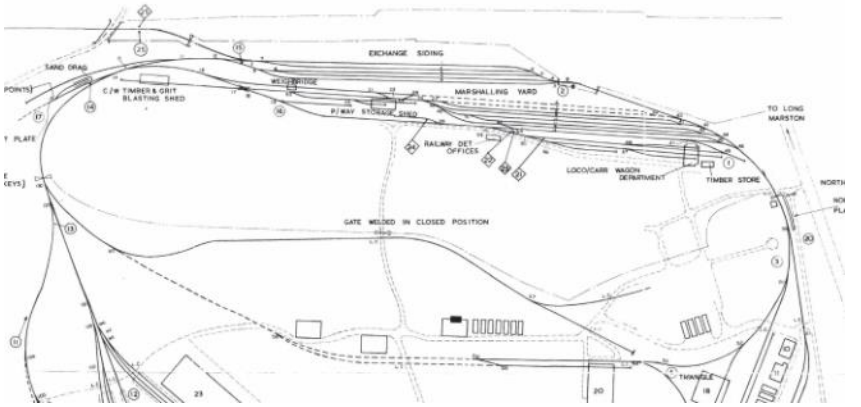
Capacity for Rail

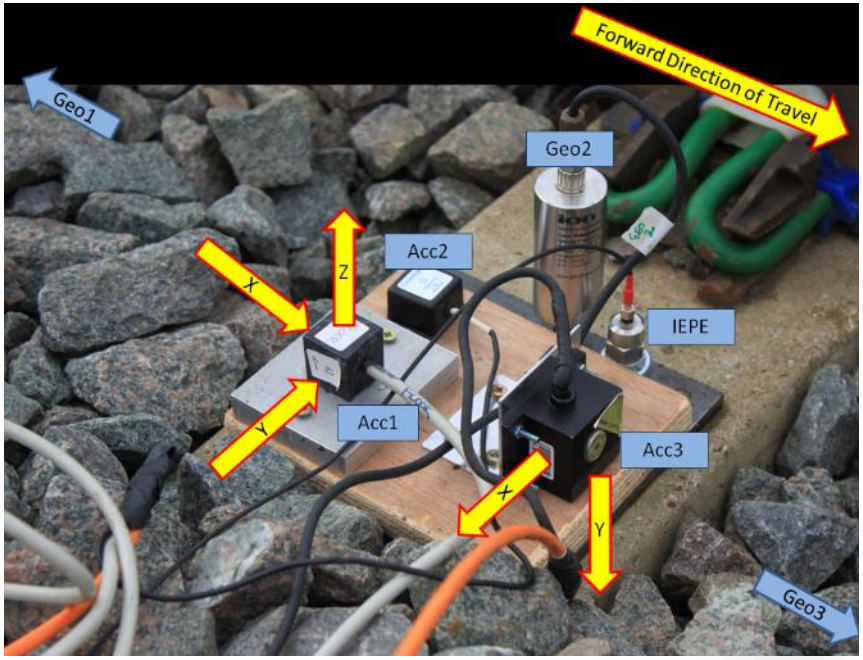
Testing has been undertaken at the Long Marston facility

A variety of different grade (cost) accelerometers have been evaluated

Testing for both direct vibration, but also suitability for displacement sensing

Cross-comparison of sensors and evaluation against geophones



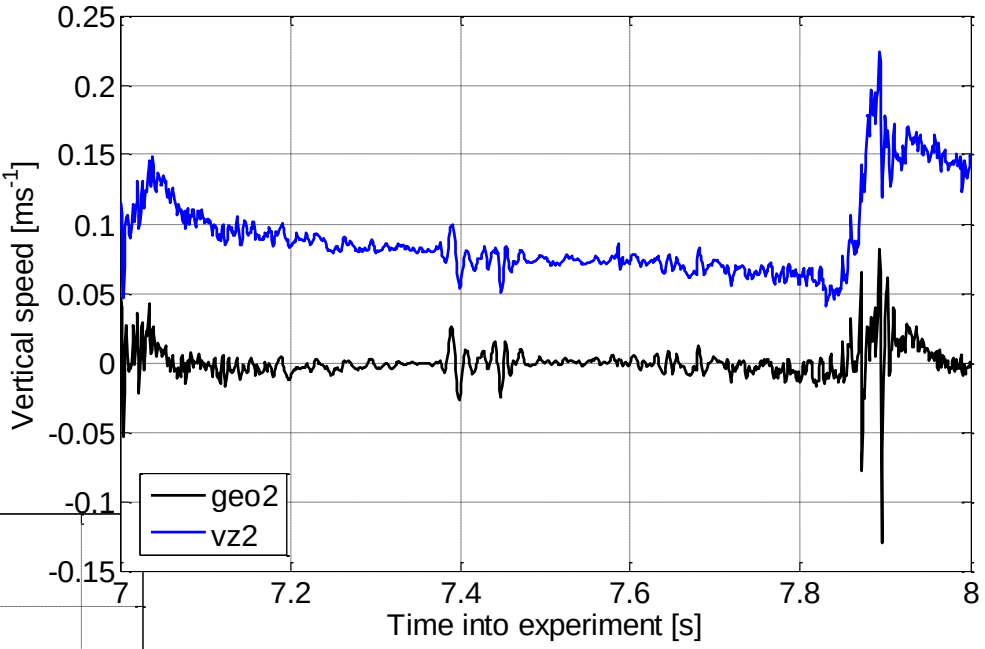


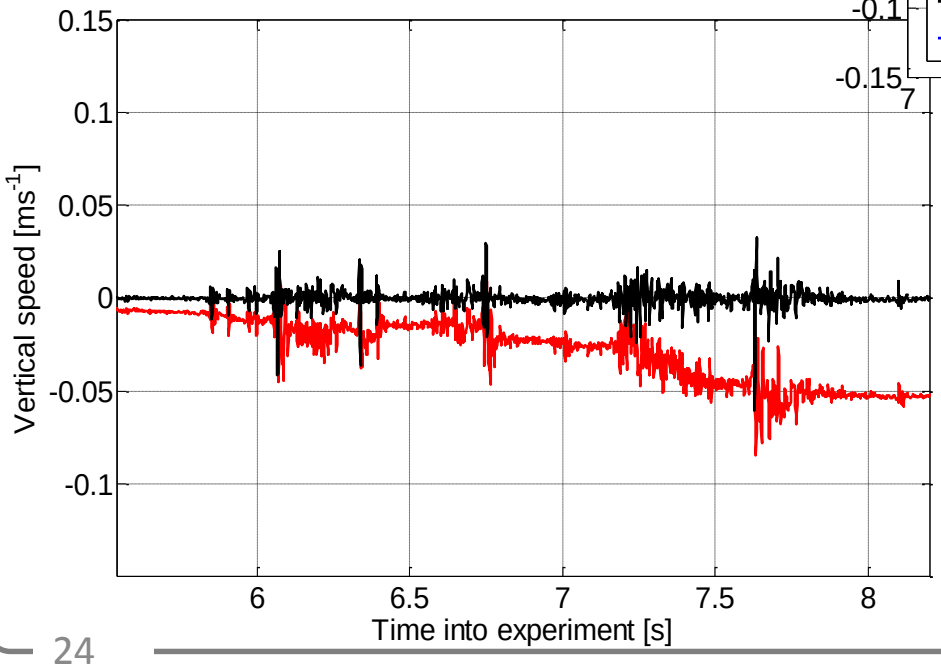
Sensor Evaluation / Comparison

Capacity for Rail

High quality (cost) sensor displays reasonable correlation

Key sensor attribute is stability for this application



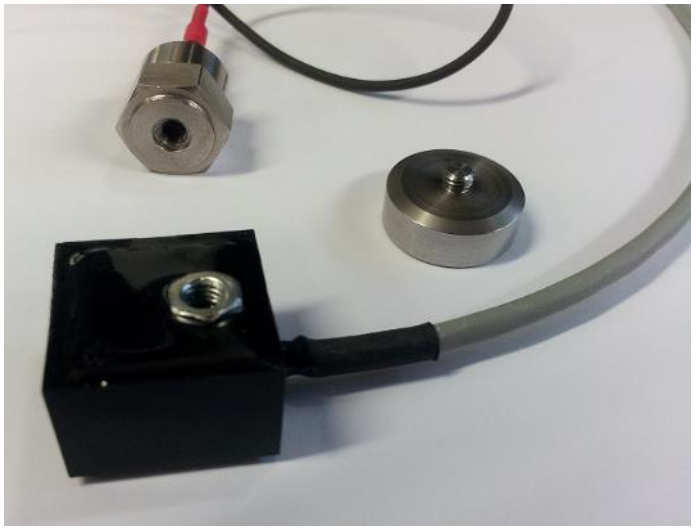


Lower quality (cost) sensor displays significant drift

Also may be affected by significant events in the signal

Accelerometers

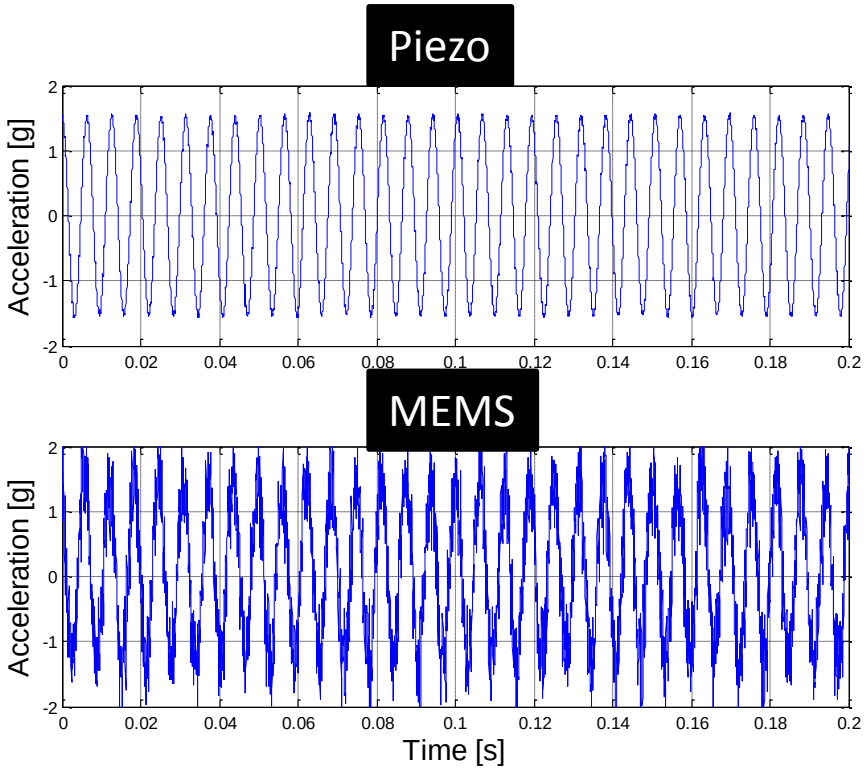
- MEMS vs Piezo
  - MEMS average draw of 0.75 mW compared to Piezo of 132 mW
  - MEMS Peak draw of 5 mA (1.5 mW)



	KS76a (Piezo)	ADXL001 (MEMS)
Interface	IEPE	Voltage
Power	~ 132 mW	< 1 mW
Range	±120 g	± 250 g
Resonant frequency	> 34 kHz	22 kHz
Sensitivity	50 mV/g	4.4 mV/g
Noise	80 µg (20 – 50000 Hz)	95 mg (100 – 400 Hz)

Sensor Evaluation / Comparison

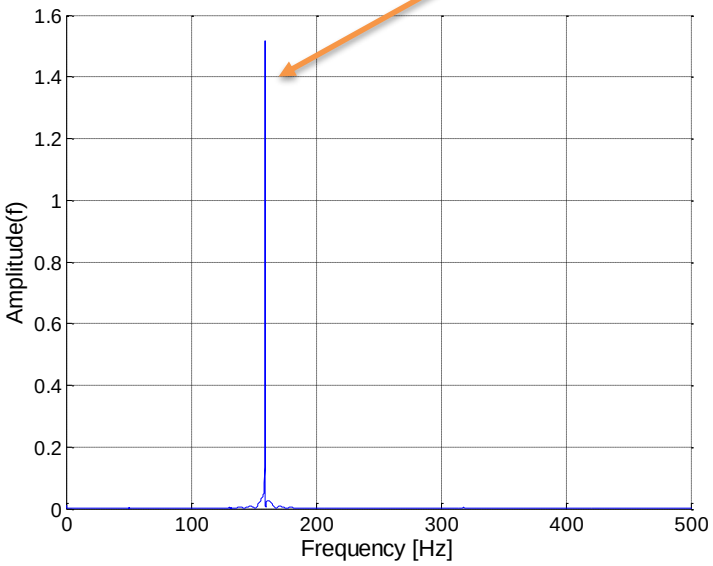
Vibration calibrator



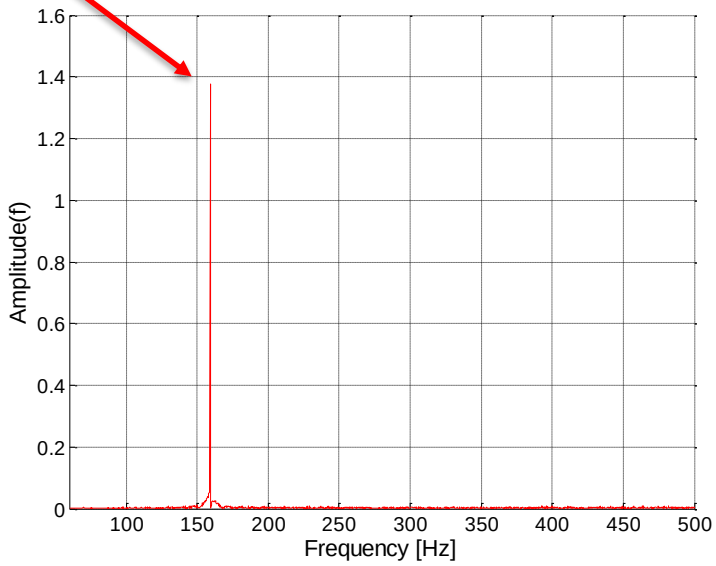
Sensor Evaluation / Comparison

- Good match
- Lower SNR but negligible

159.2 Hz calibration signal



Piezo



MEMS

Sensor Evaluation

- Using the SP4 – WP4.2 proposed evaluation framework

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WEIGHT	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	
S1 MEMS Accelerometer ADXL345	10	10	10	10	10	5	10	10	0	0	10	10	0	10	10	5	10	10	10	10	10	5	**8.0**

Energy Systems

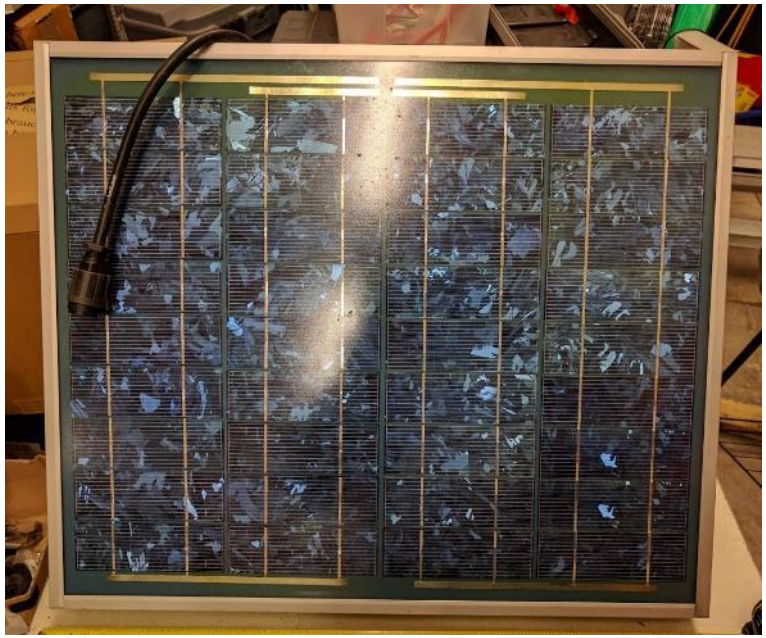
- Rugged solutions for different weather conditions
- Up to 40W power

ENERGY HARVESTING								
Ref	Description	Suitability for installation at different sites	Monitoring and reporting of battery status	Self-diagnostic	Environmental compatiblity	Resistance to electromagnetic fields	Mounting simplicity	**ENERGY HARVESTING SCORE**
	Weight	17%	17%	17%	17%	17%	17%	
E1	LE-v50 wind turbine	5	5	5	5	10	10	**6.7**

- Rugged wind turbine
- Storm-proof
- Dust and debris resilient
- Wide temperature range

Energy Systems

- 50 cm automotive solar panel (traffic lights)
- Up to 20W power



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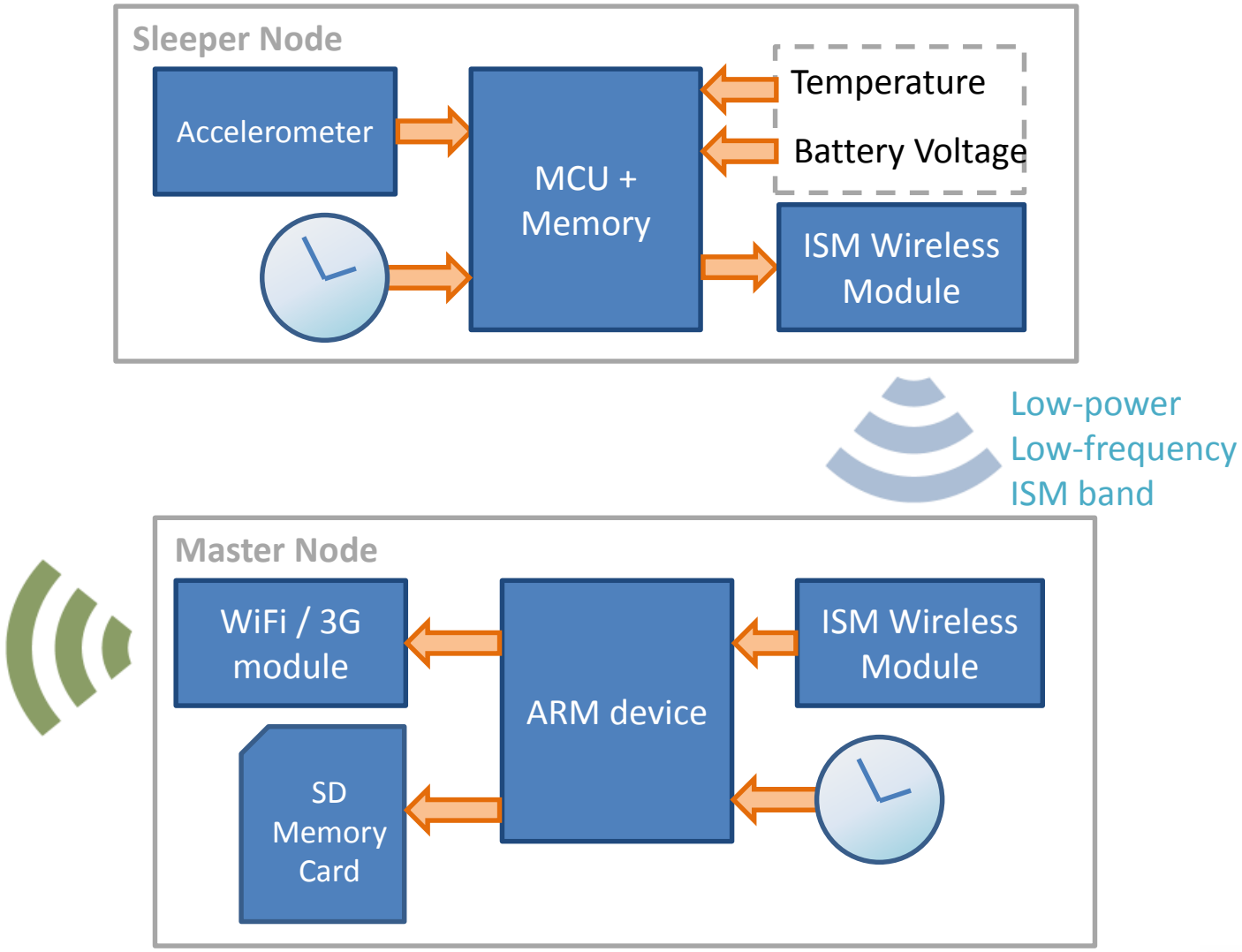
	Weight	17%	17%	17%	17%	17%	17%	
E1	Solare panel BP SX20U	5	5	0	5	10	10	**5.8**

- Wide operating temperature range
- Resilient unit, does not require further housing / protection

UoB Wireless Node System Overview

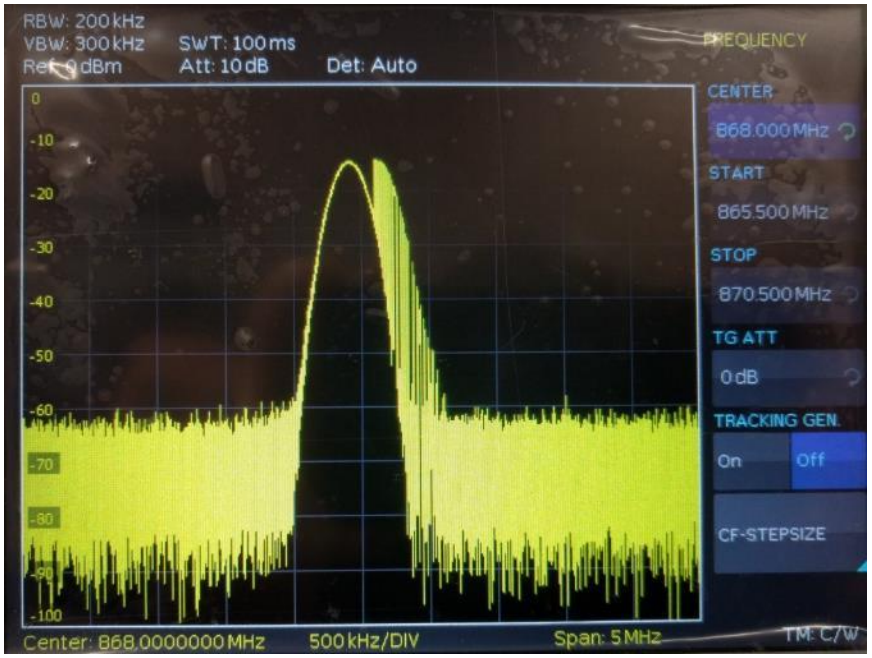


UoB Sleeper node

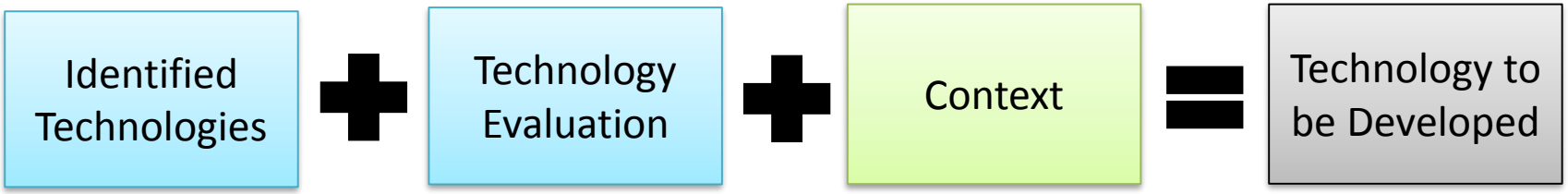
- Easily deployable networks of sensors
- Internal accelerometer
- ‘Sleeps’ until a train is detected
- Samples at 1600 Ss^{-1}
- Downsamples to 800 Ss^{-1}
- Stored in local memory
- Transmitted to master node after train has passed
- Battery powered
  - ~5 years
  - EH for local master node

Inter-node Communications

- Low frequency ISM band
- 868 MHz FSK
- Very low power
- Each node transmits at specified time slot – time division multiplexing
- Real-time clocks are periodically synchronised by the master



Technology Evaluation



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Field Testing / Demonstration Activities

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UoB - Live Trial Initial Tests

- Monitoring sleepers on the UK HighSpeed 1 line using low power accelerometers and embedded microcontrollers
  - Eurostars
  - Javelins
  - Freight trains
- Monitoring the noise signature pre/post grinding
  - Use of lower power microphones and embedded system

UoB - Live Trial Initial Testing

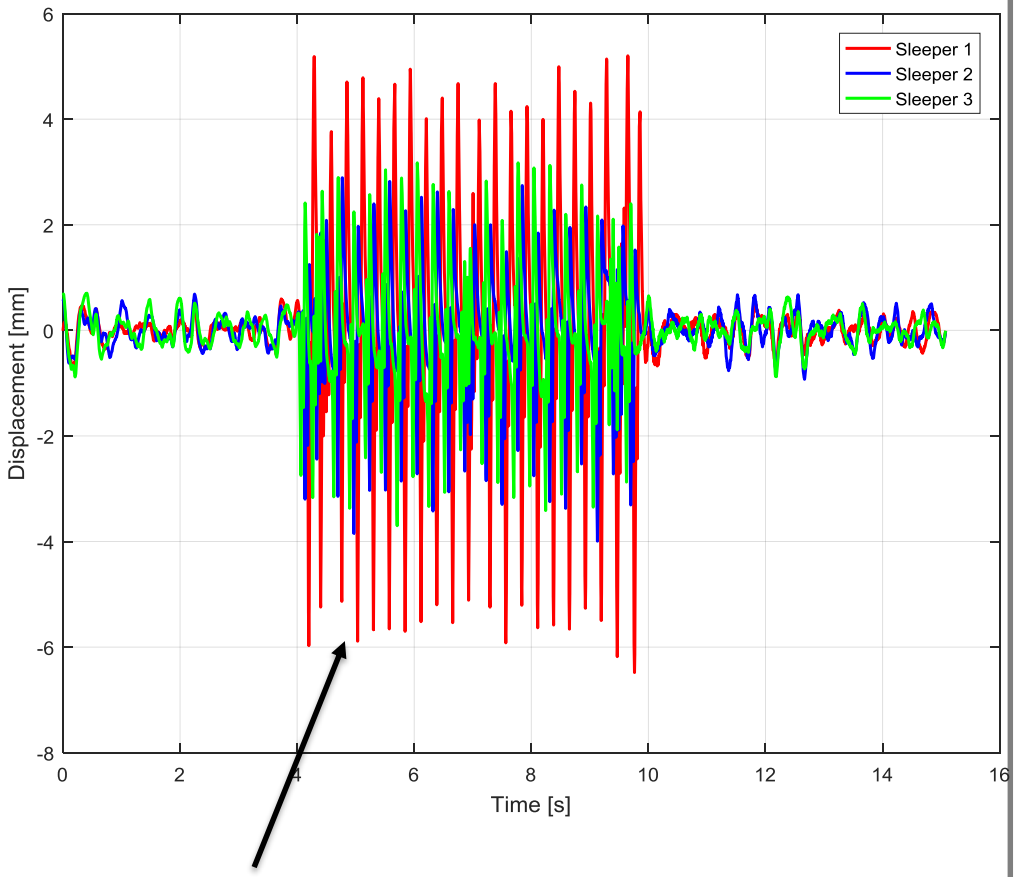
- 3 accelerometers installed on the UK HighSpeed 1 line
  - Line speed

    220 kph to 300 kph

- Around 1400 train passages were recorded over a 2 week period

Data Analysis - Accelerometers

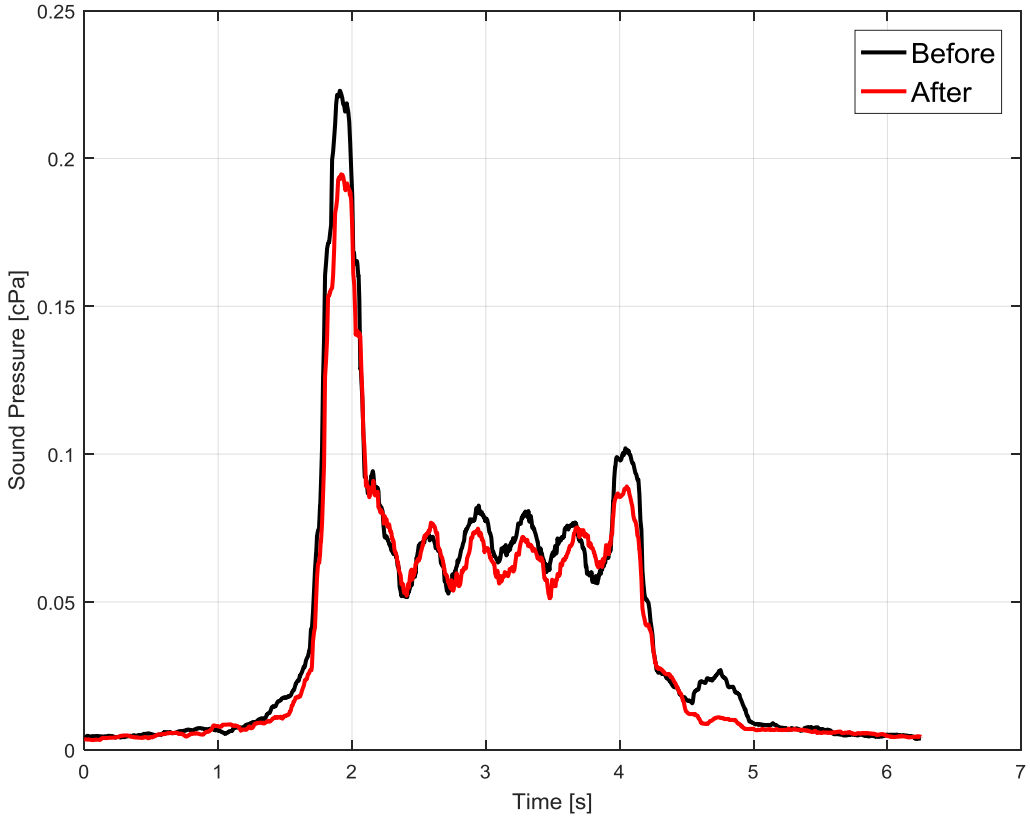
- Displacement curves for the three accelerometers
- One is significantly larger than the other two



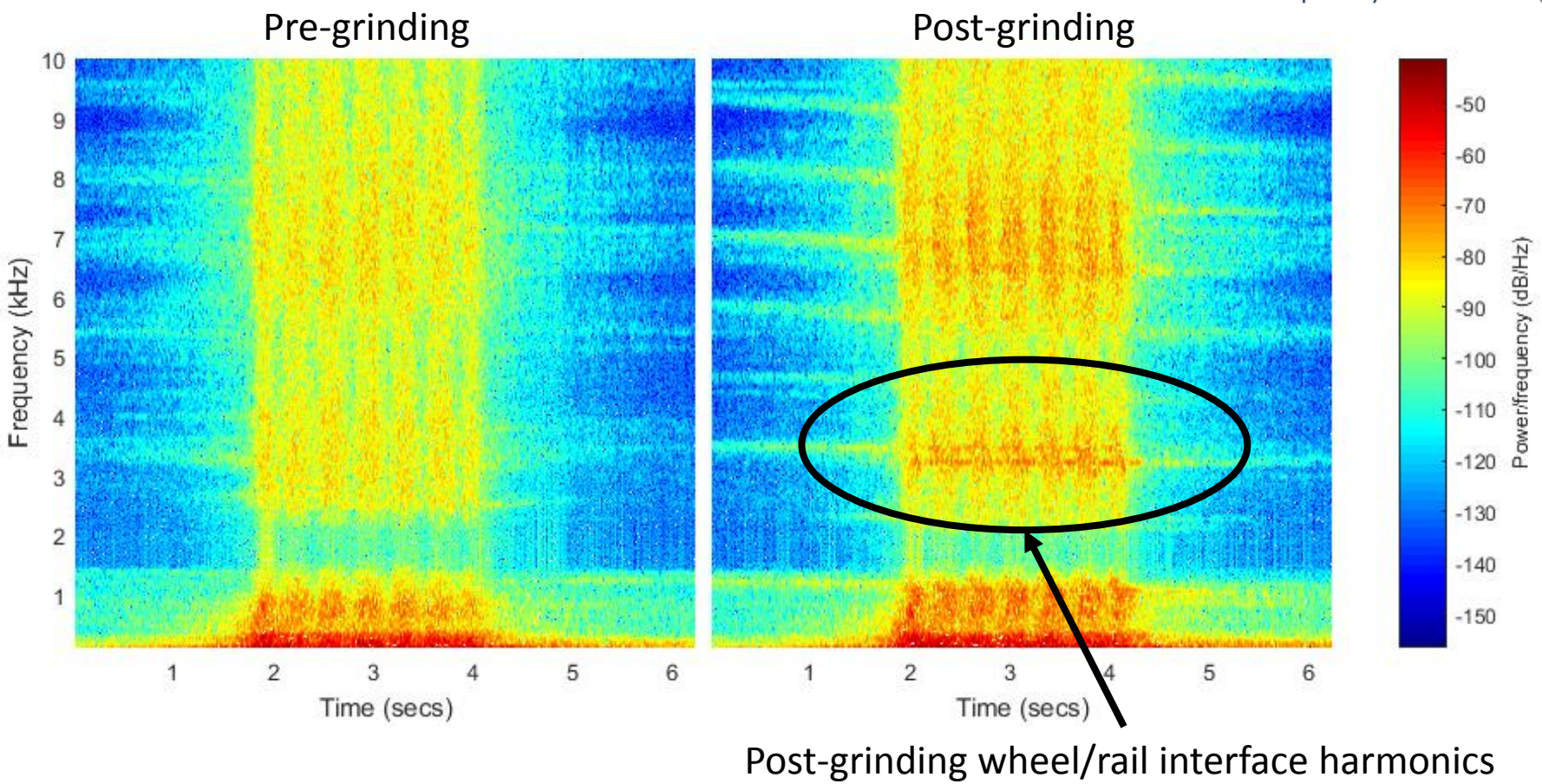
Less-well supported sleeper

Data Analysis – Sound Pressure

- Before and after rail griding
- Lower RMS values in the sound pressure level after grinding



Rail Grinding – Sound Pressure



- Overall level slightly reduced (<3dB)
- Noise distributed over wider frequency range
- Some wheel / rail effects to be considered

Future Plans

- Transition zone monitoring into or out of a tunnel
- Approval granted for 16 nodes

North Downs Tunnel – HS1

Future Plans

- Transition zone onto a bridge
- Bridge structure
- Instrumentation developed
- Awaiting approvals

New Sado river crossing

Conclusions

- SP4 has developed technology review methodologies
  - Mechanisms for identifying
  - Frameworks for evaluating
- Key technologies have been tested
  - Paper exercises
  - Laboratory testing
  - Preliminary field trials
- Selected technologies are being taken forward for full field testing evaluation

Thank you for your kind attention

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The University of Birmingham

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