

# Understanding and mitigating MSD risks faced by frontline rail-staff using wearable technology

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## SUMMARY

Musculoskeletal disorders (MSDs) are a major contributor to sickness absence and reduced operational performance among front-line rail staff. This study applied a validated workwear-integrated wearable-sensor system to quantify real-world ergonomic risks associated with key manual-handling and passenger-support tasks performed by Conductors, Passenger Companions and Catering Hosts. Continuous kinematic data identified posture-related hazards, forceful exertions and technique drift between training and operational settings. Evidence-based mitigations are now being implemented, including enhanced training, improved training fidelity, redesigned storage layouts, infrastructure modifications and equipment evaluations. Strong engagement from staff, operational leadership and trade unions demonstrates the value of objective ergonomic assessment in informing practicable MSD-risk reduction strategies and supporting safer, more inclusive working environments.

## KEYWORDS

Musculoskeletal Disorders, risk assessment, sensors, rail industry, front-line staff

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## Introduction

Musculoskeletal disorders (MSDs) remain a major cause of ill-health within the UK rail industry, contributing to approximately one in four days of sickness absence and costing the sector an estimated £89 million annually (ORR, 2019; RSSB, 2024). Previous large-scale surveys highlight the magnitude of the issue: nearly half of respondents to the RSSB Mental Wellbeing Survey reported backache (48%), upper-body pain (54%) or lower-limb discomfort (43%) in the previous 12 months (RSSB, 2021). The more recent industry-wide MSD survey reinforced these findings, with 94% of rail workers reporting musculoskeletal trouble in at least one body region and the lower back identified as the most affected (64%) (Huysamen et al., 2025). Despite this prevalence, MSDs remain frequently underreported due to cultural beliefs that pain is “part of the job”, concerns regarding managerial response, and a lack of confidence that reporting will lead to meaningful change.

Front-line customer-facing roles including Conductors, Passenger Companions and Catering Hosts, carry out frequent manual-handling and mobility-support tasks in dynamic environments. These tasks include ramp deployment, wheelchair assistance, and trolley manoeuvring, all of which present multiple ergonomic risk factors such as trunk flexion, horizontal reach, exertions, and cumulative loading. Historically, these roles have lacked objective, task-level risk data. Advances in wearable sensor technology now enable continuous kinematic monitoring embedded directly into workwear, providing granular, real-world ergonomic risk profiles. This study applied a validated

workwear-integrated sensor system to quantify MSD-related risks among front-line rail staff and to identify practicable, evidence-based mitigations.

Assessing MSD risks and reducing them to As Low As Reasonably Practicable (ALARP) requires objective measurement of the physical demands placed on staff. The Health and Safety Executive (HSE) tools; Manual Handling Assessment Charts (MAC) (HSE, 2018) and Risk Assessment of Pushing and Pulling (RAPP) (HSE, 2016), provides valuable frameworks for assessing various contributing risk factors relating to lifting & carrying and pushing & pulling tasks respectively. However, they rely on visual observations. Traditional observational tools rely on single-posture “snapshot” assessments, which are subjective and limited in their ability to capture cumulative exposure and real operational variability (A.D.J., 2002). To address these limitations, this study employed continuous wearable-sensor-based posture monitoring combined with biomechanical modelling. Data were collected using a workwear-integrated inertial-sensor system developed by SpatialCortex Technology Ltd. The system incorporates nine inertial measurement units (IMUs) embedded within standard workwear at key anatomical locations (upper and lower limbs and torso region). This configuration enables continuous measurement of joint orientation, trunk kinematics, and whole-body posture during live operational tasks. Verification studies have demonstrated the accuracy in lab-based environments and application of this system for continuous MSD risk assessment in rail operational environments (Nandakumar et al., 2025).

## Methodology

The study examined representative manual-handling activities performed by Conductors, Passenger Companions, and Catering Hosts:

- a) Ramp deployment, retrieval from onboard storage, carrying, and stowing across multiple rolling-stock classes
- b) Wheelchair assistance, including movement across platforms and over train-platform ramps
- c) Catering trolley manoeuvring, including traversing platform-end ramps and station crossings.

Six frontline staff were assessed while performing the specified tasks across multiple rolling-stock classes. Participant characteristics and operational context are presented in Table 1. The trainee conductors performed the ramp deployment activity in both classroom training environments and in real operational environments.

Table 1: Study Participants, anthropometric percentiles, job roles and assessment locations

Train type	Staff demographics and role			Location
Class 153	F, 32 <sup>nd</sup> percentile	45-54 years	Catering host	Carmarthen station
Class 197	F, 77 <sup>th</sup> percentile	45-54 years	Catering host	Carmarthen station
Class 166, 221	F, 85 <sup>th</sup> percentile	35-44 years	Passenger Companion	Cardiff Central station
Class 153	M, 25 <sup>th</sup> percentile	25-34 years	Trainee conductors	St. Patrics House (SPH) training facility, Cardiff central
Class 153	M, 75 <sup>th</sup> percentile	25-34 years	Trainee conductors	
Class 153	F, 75 <sup>th</sup> percentile	25-34 years	Trainee conductors	

Data collection and interpretation were aligned with established frameworks, including the HSE Manual Handling Assessment Charts (MAC) (HSE, 2018) and Risk Assessment of Pushing and Pulling (RAPP) tools (HSE, 2016) and were complemented by cumulative-loading concepts informed by fatigue-failure theory (Gallagher & Sesek, 2017).

Primary biomechanical exposure metrics included:

- Trunk flexion, lateral lean, and axial twist
- Horizontal reach distance relative to the lumbosacral joint
- Vertical lift height
- Movement repetition and task duration

Load-related parameters were derived from equipment datasheets.

- The weight of the rail ramp used in this study was approximately 10 kg, while most commercially available rail ramps typically range between 10–15.5 kg (Portaramp, 2021).
- The empty standard weight of the wheelchair used was 29Kg (Staxi. 2014), with added weight of the passenger assisted and luggage.
- The empty standard weight of the catering trolley is 42Kg (Sovereign. u.d), with a fully laden weight: 80-90Kgs

These were supplemented by appropriate load estimates and static push/rolling-resistance measurements obtained using a calibrated handheld force gauge. Task frequency was inferred from operational duty cycles.

**Biomechanical Analysis:** Posture data derived from the MOVA wearable-sensor system were further analysed using a quasi-steady sagittal-plane biomechanical modelling approach to estimate joint loading. The MOVA biomechanical analysis tool represents the human body as a linked five-segment planar chain (shank, thigh, trunk, upper arm, forearm/hand), with anthropometric segment proportions scaled to individual stature. Static inverse dynamics are solved sequentially from the distal hand to the ankle to compute joint reaction forces and net joint moments at the elbow, shoulder, hip, knee and ankle. L5/S1 compressive force is estimated through a moment balance about the L5/S1 location along the trunk segment, incorporating upper-body segment weights, externally applied hand loads and an assumed extensor moment arm. Joint strength capability is evaluated using empirically derived sagittal-plane maximum moment prediction equations (Chaffin.D.B, 2006), incorporating gender-specific scaling and coefficients of variation. Percent population capable is calculated assuming normally distributed strength capacity and reported on a 0–100% scale consistent with 3DSSPP methodology (UoM, 2024). The tool is intended for static task screening and comparative ergonomic analysis rather than dynamic or three-dimensional modelling, due to the quasi-static sagittal-plane assumption.

## Results

### ***Ramp deployment***

Continuous wearable-sensor data collected during ramp deployment and retrieval identified elevated postural and ergonomic risk exposures across all rolling-stock classes or train types assessed (Classes 153, 166, 197 and 221). Among experienced staff, peak trunk flexion frequently exceeded 70°, with staff spending approximately 30% of task duration at high trunk flexion. These exposures were most pronounced during, placement at the train–platform interface, retrieval following use, and initial lifting from storage (Figure 1).

Class-specific differences were evident. For Class 197, the ramp configuration incorporates a separate bridging plate in addition to the primary ramp. Deployment of this configuration resulted in an additional 2 bending and squatting cycles per task compared to single-piece ramp designs (Figure 2). This increased repetition can lead to higher cumulative exposure to trunk flexion and lower-limb loading across a shift, consistent with fatigue-failure risk models (Gallagher & Heberger, 2013).

Retrieval of ramps from onboard storage consistently required combined lateral lean and trunk flexion, indicating postural constraint imposed by storage geometry rather than individual technique alone. Lateral trunk lean and combined flexion–lean postures were also observed, with peak lateral lean angles of 30° occurring during asymmetric handling phases, particularly when ramps were lifted from constrained storage locations. Horizontal reach distance relative to the lumbosacral joint increased substantially during ramp positioning, with mean reach distances of 60 cm, contributing to elevated spinal loading. These findings align with industry-wide MSD data identifying the lower back as the most frequently affected body region among rail workers (Huysamen et al., 2025).

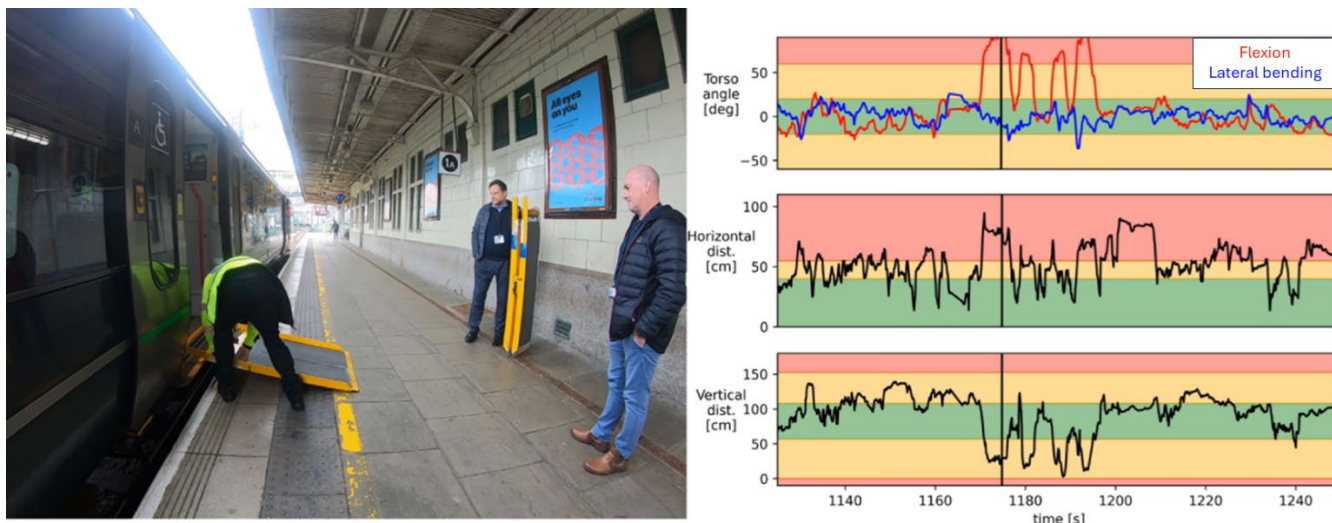


Figure 1: Ergonomic risk factors measured using work-wear integrated sensor data from staff deploying rail ramps on a Class 166 train

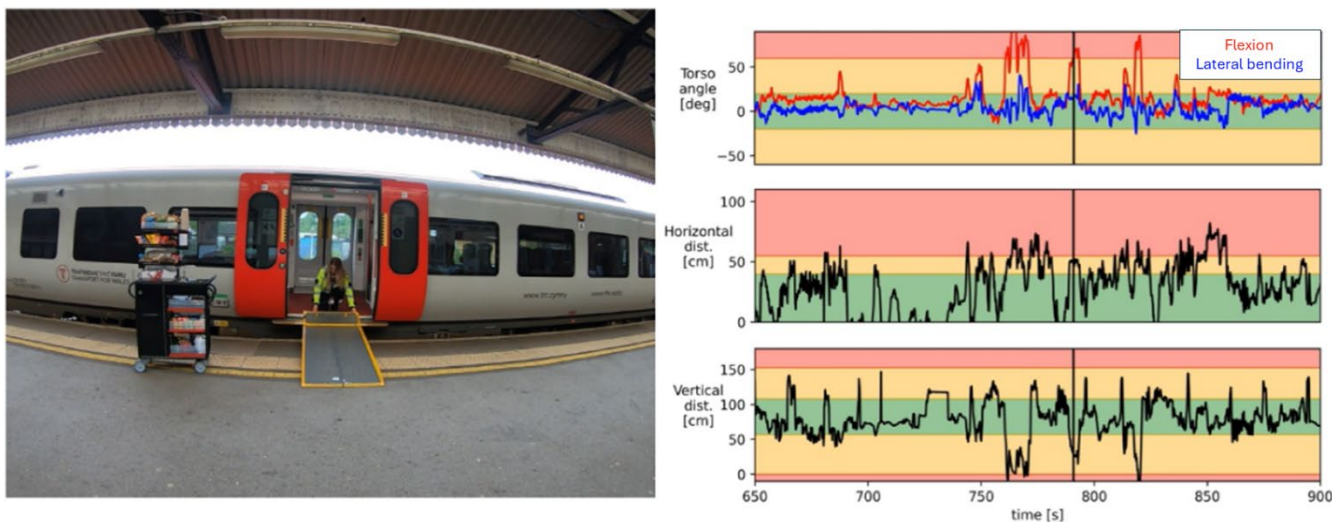


Figure 2: Ergonomic risk factors measured using work-wear integrated sensor data from staff deploying rail ramps with the bridging plate on a Class 197 train

**Ramp deployment: Training-to-operation technique drift**

Comparison of wearable-sensor data from training and live operational environments revealed marked technique drift among trainee staff, particularly for Class 153 ramp deployment. In controlled training settings, trunk flexion angles momentarily exceeded 60°, with task durations averaging 20s. In contrast, real-world deployments demonstrated sustained peak trunk flexion exceeding 65°, with total task duration increasing by a factor of 2–3×.

A key contributor to this divergence was the presence of positioning pins on operational ramps, which were absent from training ramps at the time of assessment. Especially on the particular Class 153, door-ramp interference frequently required forceful manipulation and prolonged awkward postures to achieve correct pin alignment and engagement. Sensor data indicated that more than 50% of the total task duration was spent in sustained trunk flexion and lateral lean which aligned with pin location and engagement phases.

These findings demonstrate that task constraints, rather than deficiencies in training knowledge, were the primary drivers of increased ergonomic risk, highlighting the importance of training fidelity and realistic task simulation.

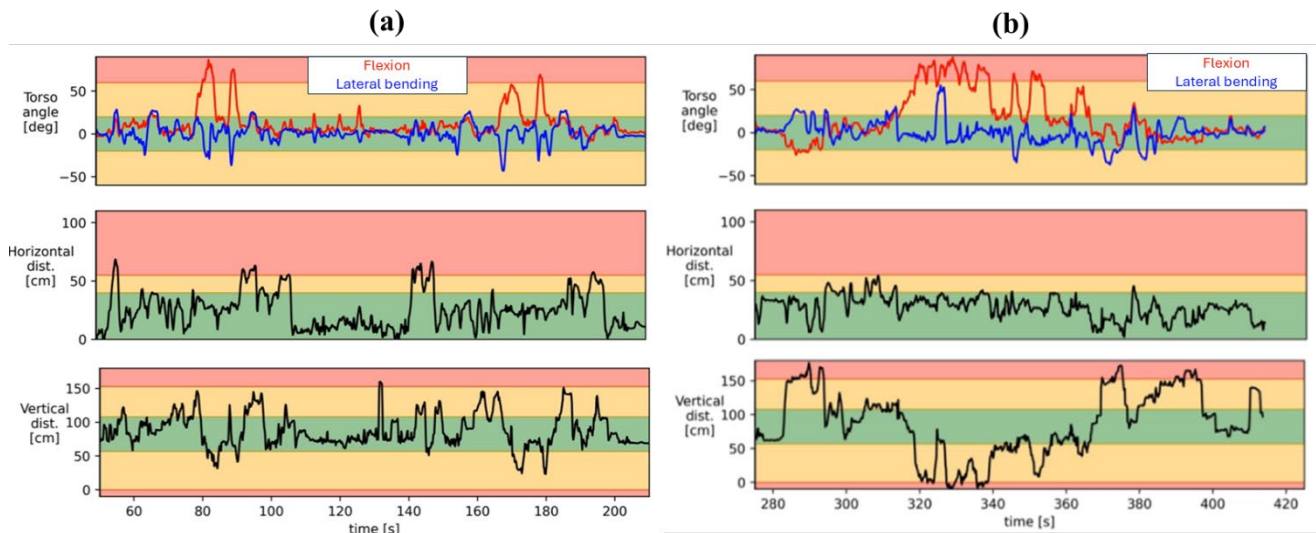


Figure 3: Ergonomic risks during rail ramp deployment (a) training environment vs (b) operational environments

### **Wheelchair assistance**

Wearable-sensor assessments of wheelchair assistance tasks performed by Passenger Companions identified multiple ergonomic risk factors associated with both ramp-assisted and level-surface movement. Elevated trunk flexion and lateral lean were observed during ramp deployment, wheelchair positioning, and initiation of movement. Peak trunk flexion frequently exceeded  $70^\circ$  during ramp setup and exceeded  $45^\circ$  during initial wheelchair push phases.

Initiation of wheelchair movement characterised by high force demands, saw staff adopting forward-leaning postures to overcome static resistance.

Force demand is influenced by several parameters, including ramp gradient, combined system mass (wheelchair, passenger and luggage), equipment condition and ground surface characteristics. The initial push force required to mobilise an empty wheelchair on a representative level platform surface was measured at approximately 15 N. Assuming a 95th percentile male passenger mass of 98 kg, the estimated initial push force on a level surface increases to approximately 66 N, reflecting increased rolling resistance with higher normal load. When manoeuvring the wheelchair up a ramp, the required push force additionally includes the gravitational component acting along the slope. For a ramp gradient of 1:10 ( $\approx 5.71^\circ$ ), the estimated quasi-static force required to initiate upward movement is approximately 197 N. This approaches the HSE guideline value of 200 N for men and exceeds the recommended 150 N for women (HSE, n.d).

The ACC NTSN specifies that on-board ramps shall be designed and assessed for use within a maximum slope of 18% ( $10.2^\circ$ ) (DfT, 2025). Estimating push demands at this regulatory slope

indicates the quasi-static force to initiate upward movement is approximately 286 N, exceeding HSE guideline values for initiating push/pull forces (HSE, n.d).

In addition to force and postural exposure, wheelchair assistance tasks often required Passenger Companions to carry ramps over extended distances between storage locations and deployment points. These carry tasks involved repetitive lifting and carrying with limited opportunity for posture recovery, increasing cumulative loading across a shift.

### **Catering trolley manoeuvring**

Ergonomic assessment of catering trolley manoeuvring identified significant postural and force-related risk exposures during platform movement, ramp negotiation, and station crossings. Sensor data indicated elevated trunk flexion and shoulder loading during initiation of trolley movement, particularly where rolling resistance or surface irregularities were present.

Similar to wheelchair handling, the force demand associated with pushing or pulling catering trolleys is influenced by ramp gradient, combined system mass (trolley and goods), equipment condition, and ground surface characteristics. For a fully laden trolley weighing approximately 80 kg, the initial force required to initiate motion on a level platform was measured at 39 N. On a platform-end ramp with an incline of approximately 4.5°, the required force increased to 100 N. Extrapolating to a ramp gradient of 1:10 ( $\approx 5.71^\circ$ ), the estimated push/pull force remains in the order of 117 N. At the NTSN's maximum of 10.2°, the force demand is estimated as 177N exceeding HSE guideline values for initiating push/pull forces for women and approaching those for men (200 N for men; 150 N for women). The risk is further elevated where the task is performed using a single-handed pull, which increases asymmetrical loading and shoulder moment demand.

At Carmarthen station, catering trolleys are transported between platforms via the barrow crossing in the absence of a pedestrian bridge or other grade-separated access. Catering hosts were observed lifting the trolley momentarily to traverse a barrow crossing.

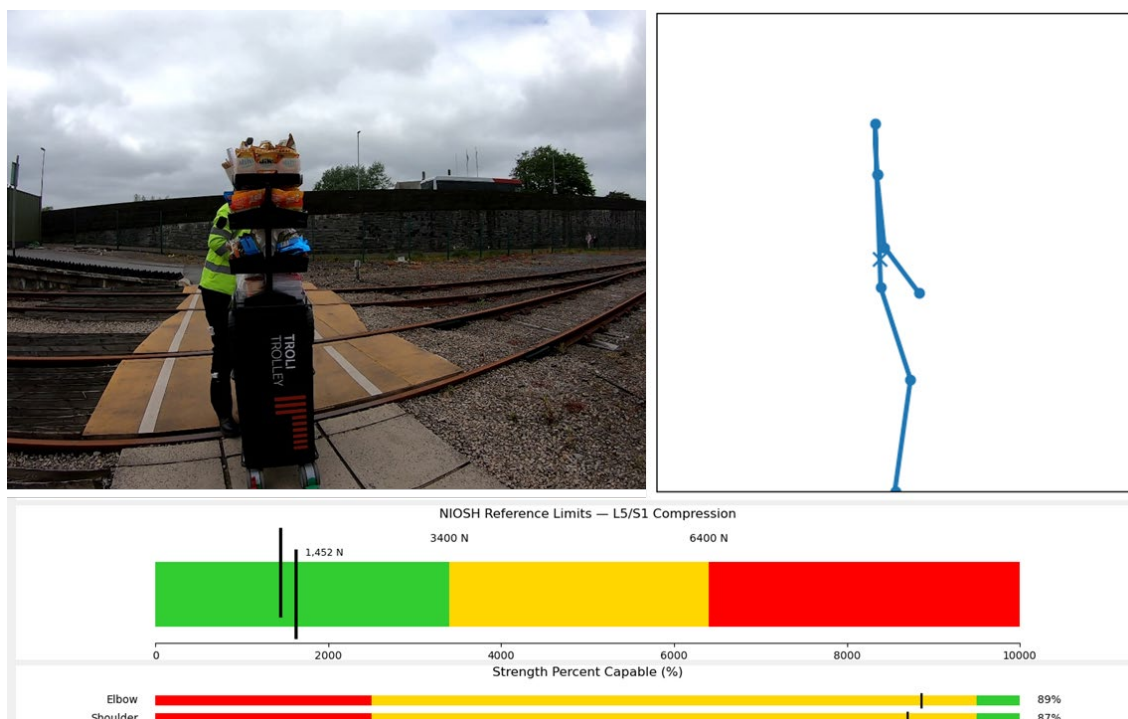


Figure 4: A catering host traversing a trolley across a barrow crossing at Carmarthen station – Sagittal plane Biomechanical analysis

In this study, the biomechanical model was applied to estimate shoulder joint moments during catering staff barrow-crossing tasks. Workwear-integrated sensor data indicated that, during traversal of the crossing, the horizontal (distal) distance between the shoulder joint and the load ranged from approximately 24–32 cm. To clear structural gaps in the crossing, staff were required to momentarily lift the trolley, with the lifted portion estimated at 30–50% of the total load mass. Although the task was performed using a two-handed grip, asymmetrical posture and load distribution were observed, resulting in estimated net shoulder moments ranging between 29–62 Nm under quasi-static assumptions. For comparison, population-based shoulder torque capacity data for females indicate that the 25th to 95th percentile range spans approximately 28–50 Nm (Dickerson, 2006). The upper range of the estimated shoulder moments therefore approaches or exceeds the strength capacity of a substantial proportion of the population. These findings confirm the presence of elevated shoulder loading during trolley lifting manoeuvres associated with structural deficiencies in the barrow crossing.

Comparative assessment of push versus pull techniques revealed that, despite trolley design favouring pulling for stability, staff frequently adopted pushing strategies, particularly when negotiating shallow platform-end ramps. Staff feedback and posture data suggested reduced perceived exertion and improved body mechanics when pushing, including greater use of lower-limb and core musculature and reduced upper-body loading.

## **Discussion: ALARP-based interpretation and mitigations**

### ***Ramp deployment***

The ergonomic risk profiles identified during ramp deployment indicate sustained exposure to postures and task characteristics associated with elevated MSD risk, particularly for the lower back. Peak trunk flexion angles exceeding 70°, prolonged duration above risk thresholds ( $\approx 30\%$  of task time), and repeated bending cycles, especially for Class 197, represent contributors to cumulative musculoskeletal loading. Within an ALARP framework, these findings necessitate the identification and implementation of reasonably practicable risk-reduction measures.

The data demonstrated that a substantial proportion of the observed risk exposure was driven by task and equipment constraints rather than individual handling technique alone. This distinction was critical in guiding mitigation strategy selection. Where risks were attributable to knowledge or skill gaps (e.g. inconsistent technique among experienced staff), training-based controls were considered reasonably practicable and proportionate. Where risks arose from discrepancies between training and operational environments, most notably the absence of positioning pins in training, improving training fidelity represented a low-cost, high-impact control and was prioritised.

Design-based interventions were also evaluated in line with the hierarchy of control. The one-piece aluminium ramp prototype trialled for Class 197 sought to eliminate additional handling steps associated with the bridging plate and thereby reduce cumulative postural exposure. However, ergonomic assessment identified that the increased ramp mass (approximately 35% greater than the existing configuration) introduced higher manual-handling demands, while the swivel-wheel mechanism reduced stability during movement. In ALARP terms, this design did not represent a net risk reduction and was therefore not taken forward.

Similarly, storage-geometry constraints contributing to combined flexion–lean postures were identified as a design limitation rather than a behavioural issue. While short-term mitigations focused on training and technique optimisation, the findings provide an evidence base to inform future rolling-stock design specifications and storage-layout decisions.

The mitigations currently being implemented, enhanced and refresher training, a “train-the-trainer” programme, improved training fidelity through realistic ramp configurations, and closer sequencing of classroom and operational training, were selected as measures that are both effective in reducing exposure and reasonably practicable within current operational constraints. Importantly, these controls target the specific task phases shown by sensor data to contribute most significantly to MSD risk.

By grounding mitigation decisions in objective, task-level ergonomic data, this approach demonstrates a transparent and defensible application of the ALARP principle. The use of continuous wearable-sensor assessment enables risk to be quantified, mitigations to be prioritised, and residual risk to be explicitly acknowledged.

### ***Wheelchair Assistance***

The identified risk profile for wheelchair assistance reflects a combination of posture-related exposure, force demands, and task frequency. Within an ALARP framework, it was critical to distinguish risks driven by unavoidable task requirements (e.g. assisting passengers with reduced mobility) from those that could be reduced through practicable controls.

Results indicated that elevated loading during wheelchair initiation and ramp negotiation was not solely attributable to individual technique but was strongly influenced by task configuration, carry distance, and storage layout. As a result, mitigations focused on reducing exposure at source where practicable. Targeted training was introduced to improve posture during wheelchair initiation, emphasising stance, controlled force application, and sequencing of movement to reduce peak loading.

In parallel, a redesign of ramp storage arrangements at Cardiff Station was approved to reduce carry distances for Passenger Companions, and it has already been implemented in Newport Station. This intervention was justified under ALARP as a low-complexity, high-impact control capable of reducing cumulative loading without introducing new risks. While further engineering controls (e.g. powered assistance) were considered, these were assessed as disproportionate at this stage relative to the level of residual risk and operational feasibility.

By combining technique-focused training with layout optimisation, the selected controls represent a proportionate and defensible approach to reducing MSD risk associated with wheelchair assistance.

### ***Catering trolley manoeuvring***

From an ALARP perspective, the risks associated with catering trolley manoeuvring were largely driven by infrastructure condition and task environment rather than individual behaviour. The requirement to lift a loaded trolley at the barrow crossing represented an unacceptable manual-handling risk and could not be justified as reasonably practicable to retain.

Accordingly, Network Rail committed to fully renewing the Carmarthen barrow crossing (scheduled from April 2026-2027), incorporating a segregated trolley lane alongside a pedestrian walkway. This engineering control directly eliminates the need for lifting and represents a clear reduction of risk at source, consistent with the hierarchy of control and ALARP principles.

Regarding technique selection, while pulling remains the nominal design intent for trolley stability, sensor data and staff feedback indicate that pushing, particularly on shallow gradients, may reduce musculoskeletal loading. However, as pushing can increase tipping risk under certain conditions, this mitigation is being approached cautiously. Further assessment and consultation are underway to determine task-specific best-practice guidance that balances ergonomic benefit against stability risk.

The combination of infrastructure renewal, evidence-informed technique guidance, and staff engagement reflects a proportionate ALARP approach, targeting the highest-risk contributors while avoiding the introduction of new hazards.

### **Regulatory alignment between ramp design standards and manual-handling risk**

The findings highlight an important interaction between accessibility design standards and manual-handling risk guidance. The HSE RAPP tool classifies ramp gradients greater than 5° as 'Red' risk category, indicating a high level of concern requiring prompt risk reduction. In contrast, the ACC NTSN permits on-board ramps to be designed and assessed for use at gradients up to 18% (10.2°) (DfT, 2025). Force estimations at 10.2° demonstrate substantially higher push demands compared with shallower gradients, with values approaching or exceeding HSE guideline limits for initiating push/pull tasks. While these standards serve different primary purposes, accessibility compliance versus musculoskeletal risk management, their intersection is operationally significant. Within an ALARP framework, gradients approaching regulatory maxima may necessitate additional controls (e.g. training, task redesign, or infrastructure improvements) to ensure manual-handling risks remain proportionate and reasonably practicable.

### **Organisational engagement and implementation**

The programme received strong support across operational and leadership levels at Transport for Wales, with:

- Extensive frontline participation and proactive feedback
- Senior leadership endorsement due to safety and efficiency benefits
- EDI stakeholder support for improving inclusivity and reducing physical barriers;
- Trade union engagement aligned with worker safety priorities.

The wider support facilitated effective implementation of mitigations and reinforced the value of objective, continuous ergonomic assessment.

### **Conclusion**

This study demonstrates the value of continuous, wearable-sensor-based ergonomic assessment in identifying MSD risks among front-line rail staff and driving evidence-based mitigations. The findings highlight task-specific posture deviations, force demands, and technique drift between training and real-world practice. The interventions implemented, including improved training, infrastructure modifications, equipment evaluations, and storage redesign, provide targeted, practicable risk-reduction measures. The strong organisational engagement and cross-industry interest further reinforce the value of integrating objective ergonomic measurement into rail health-and-safety programmes. Wearable technology offers a powerful platform for continuous improvement in MSD risk management and supports the development of safer, more inclusive operational environments.

### **Acknowledgement:**

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### **References**

Chaffin, D. B., Andersson, G. B. J., & Martin, B. J. (2006). *Occupational biomechanics* (4th ed.). Hoboken, NJ: Wiley.

- Department for Transport (DfT) (2025). *National Technical Specification Notice: Accessibility – Issue 1, May 2025*. London: Department for Transport.
- Dickerson, C. R., Martin, B. J., & Chaffin, D. B. (2006). *The relationship between shoulder torques and the perception of muscular effort in loaded reaches*. *Ergonomics*, 49(11), 1036–1051.
- Gallagher, S., Sesek, R. F., Schall, M. C., & Huangfu, R. (2017). Development and validation of an easy-to-use risk assessment tool for cumulative low back loading: The Lifting Fatigue Failure Tool (LiFFT). *Applied Ergonomics*, 63, 142–150.
- Health and Safety Executive (HSE). (2018) *Manual handling assessment charts (the MAC tool) INDG383(rev3), published 2018*
- Health and Safety Executive (HSE). (2016) *Risk assessment of pushing and pulling (RAPP) tool INDG478, published 2016*
- Health and Safety Executive (HSE) (n.d.). *Push and pull: assessment of risk*. United Kingdom: HSE. Available at: <https://www.hse.gov.uk/msd/pushpull/assessment.htm>
- Huysamen, K., McCulloch, O., Bacon, F., Widdows, J., Arnes, B. & Leach, P. (2025). *Exploring the risk and extent of musculoskeletal disorders in UK heavy rail.*, Contemporary Ergonomics and Human Factors 2025. Chartered Institute of Ergonomics and Human Factors.
- Koski, A. V., & McGill, S. M. (1994). Dynamic shoulder flexion strength: for use in occupational risk analysis and clinical assessment. *Clinical Biomechanics*, 9(2), 99–104.
- Nandakumar, A., Elhamri, M., Shah, Z., Manohara Selvan, K., Womack, S., & Carpenter, S. (2025). *Verification and application of workwear-integrated sensors for ergonomic injury risk assessment.*, Contemporary Ergonomics and Human Factors 2025. Chartered Institute of Ergonomics and Human Factors.
- Office of Rail and Road. (2019). *Closing the Gap on Health: Review of Health Risk Management in the Rail Industry (2014–2019)*. Office of Rail and Road, United Kingdom.
- Pinder, A. D. J. (2002). *Benchmarking of the Manual Handling Assessment Charts (MAC) (HSL/2002/31)*. Health and Safety Laboratory.
- Portaramp (2021). *Rail Ramp Brochure*. United Kingdom: Portaramp Ltd., UK. ([Link](#))
- Rail Safety and Standards Board (RSSB). (2021). *The Rail Industry Mental Wellbeing Survey*. London: Rail Safety and Standards Board.
- Rail Safety and Standards Board (RSSB). (2024). *Annual Health and Safety Report 2023/24: A snapshot of GB rail's health and safety performance*. London: Rail Safety and Standards Board.
- Rail Safety and Standards Board (RSSB). (2024). *Annual Health and Safety Report 2023/24: A snapshot of GB rail's health and safety performance - Health and Wellbeing Data Appendix*. London: Rail Safety and Standards Board.
- Sovereign (n.d.). *Railway Catering Trolleys*. United Kingdom: Sovereign online Ltd., UK.
- Staxi (2024). *Guest services chair Specifications Sheet*. United Kingdom: STAXI Ltd.
- University of Michigan Center for Ergonomics (UoM). (2024). *3D Static Strength Prediction Program (3DSSPP) User's Manual*. University of Michigan, Ann Arbor, MI.