

Beyond the Cab: Embedding HF in Depot Design, Operation and Maintenance

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SUMMARY

Human Factors (HF) integration in rail has matured for driving and signalling but remains underdeveloped in the long-term maintenance of rolling stock. Using HF to optimise maintenance efficiency and reduce costs associated with delays and failures requires a “system of systems” approach drawing together the human aspects of train design, design depot and depot operations.

The aim of this paper is to consolidate the authors’ experience and published material to identify commonalities. Four priorities for effective HF interventions are identified: (1) Stakeholder engagement including awareness raising (2) Published HF guidance and robust HF requirements in industry standards (3) Prioritising HF methods (based on likely scope, time and budget) to maximise impact, and (4) Improving the HF elements of incident investigations and developing design feedback loops to enable continual improvement.

This will enable the rail industry to mature in its approach to the humans who perform critical functions and help to secure resources (time and budget) for HF throughout design and operational lifecycles, thereby improving safety and reliability.

KEYWORDS

Human Factors Integration, design for maintainability, depot operations

Introduction

In the rail industry, significant Human Factors (HF) expertise has been directed toward train driving and signalling, where HF integration into new products and modification programmes is now well established. These programmes often represent the entry point for HF within the railway and, as they are established, are the most straightforward areas in which to embed good practice.

In contrast, the longer-term activities involved in maintenance of the railway and its sub-systems, e.g. rolling stock (or trains), are far less mature from an HF perspective. This aspect in relation to freight and freight yards has been discussed at length by Golightly, Lonergan and Ethell (2025) and Ryan et al (2021).

The Rail Safety and Standards Board (RSSB) (2025) describes depots, yards, and sidings as parts of the network that are often forgotten but that contribute a sizeable proportion of risks to staff. Consequently these environments and their activities do not always receive the same safety focus as operational railway lines. RSSB stresses the importance of depot work as a core part of overall rail safety. Initiatives to date include activities of the Rail Delivery Group (RDG), Depot Working Group (DWG), and National Freight Safety Group (NFSG) which bring stakeholders together to share and publish best practice, benchmarking, and improvement initiatives.

Train maintenance depots are complex and high-pressure environments where preventative, corrective and reactive maintenance must be completed within tight time windows. Poor maintenance has direct consequences: increased delay and compensation costs, reduced service reliability, reputational damage, and, in the worst cases, passenger or workforce accidents.

Train maintenance is a complex “system of systems”; those that have and can benefit from HF expertise are summarised in Figure 1.

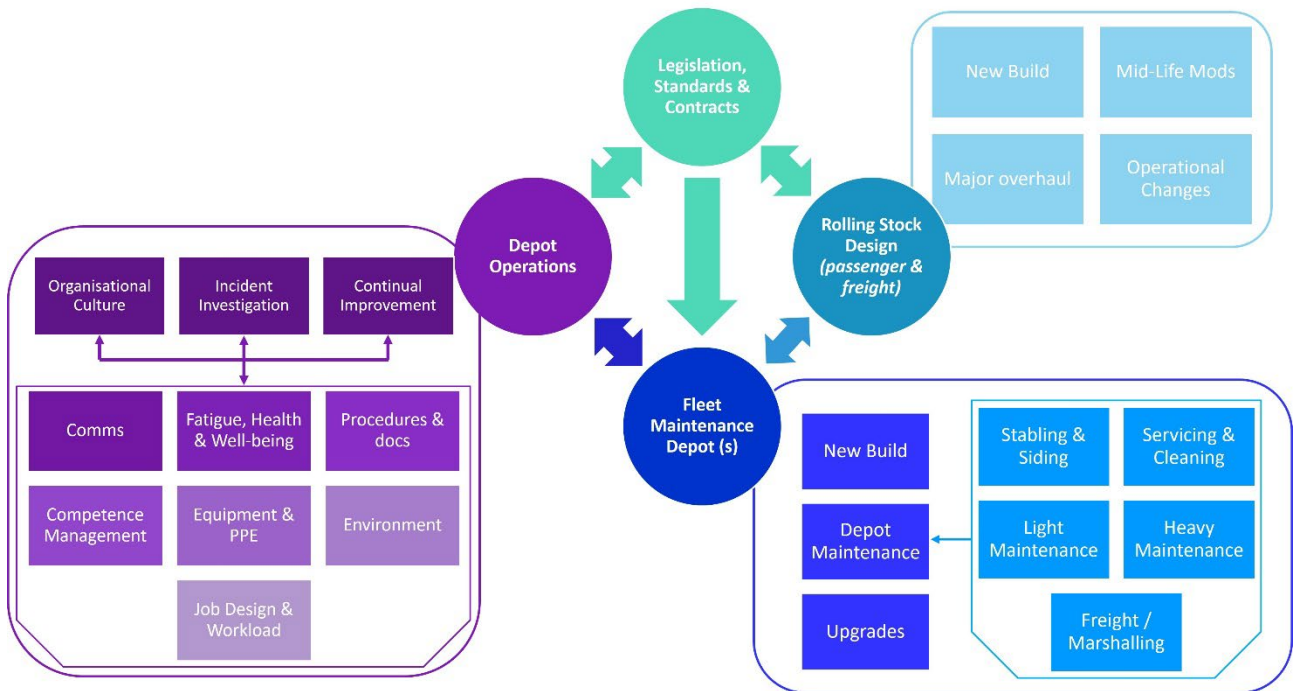


Figure 1: Train Maintenance and HF: A System of Systems

[Mods: Modifications; PPE: Personal Protective Equipment]

The aim of this paper is to consolidate the authors’ experience and relevant published material relating to train maintenance, identifying commonalities and informing industry strategy.

Vehicles and Design for Maintenance

The integration of HF in design for maintenance activities in new build trains varies considerably between Original Equipment Manufacturers (OEMs), maintenance organisations and customers. The application of HF methods must be well-timed yet flexible to respond appropriately.

New Build: HFI from Concept design

The integration of HF (HFI) from the concept design phase in new vehicles is the most effective way of ensuring an economical solution by avoiding expensive redesign, project delays and workarounds. HF requirements that are integrated with the customer contract or in referenced standards make it easier for HF to be accepted in the design lifecycle – particularly when the customer has HF specialists who are responsible for final acceptance and require sound compliance evidence.

Figure 2 summarises the HFI approach that was taken on two new build projects in the United Kingdom (UK). In both cases the customer had specific HF requirements related to maintenance, and both the customer and the OEM had established in-house HF teams.

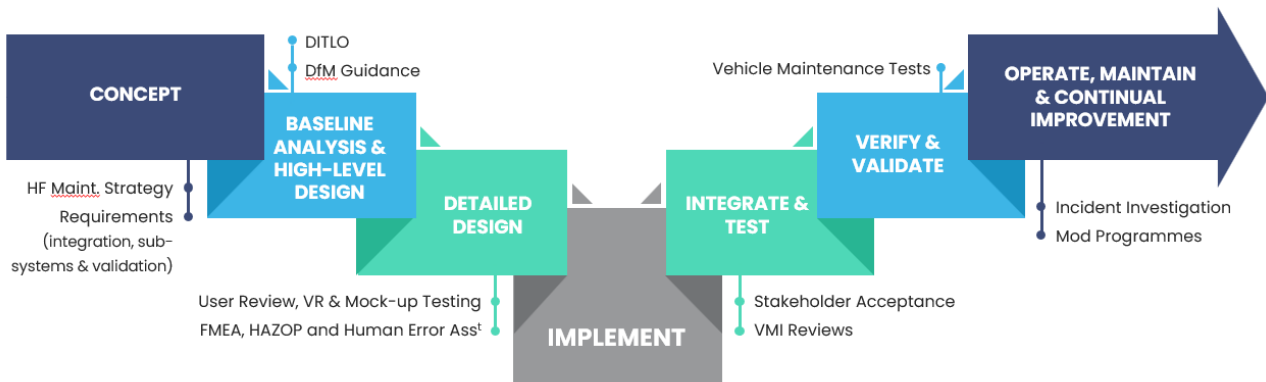


Figure 2: New Build HF Integration

[DfM: Design For Maintenance; DITLO: Day in the Life of the Train; FMEA: Failure Modes And Effects Analysis; HAZOP: Hazard and Operability Study; VMI: Vehicle Maintenance Instructions; VR: Virtual Reality]

Despite this robust approach, there were challenges to be overcome as the design process did not easily map to a traditional HFI process. Task Analysis (TA) is typically carried out in the early design stages of a project, however the vehicle maintenance instructions (VMIs), a critical input to the TA, are often not ready until the detailed design phase or later, which was the case here.

Instead, the focus was put on risk mitigation through design, and a single HF Maintenance Guidance document was produced. This consolidated relevant guidance from established standards such as British Standard Institution (BSI) standard BS EN 894 Safety of machinery – Ergonomics requirements for the design of displays and control actuators (BSI, 1997-2008), BS EN 614 Safety of Machinery – Ergonomic Design Principles (BSI, 2009) and International Organization for Standardization (ISO) standard 11228 Ergonomics Manual Handling (ISO, 2007-2022). The guide was produced for use by integration engineers and for HF to use during design reviews and testing.

In a complex system, there are hundreds of maintenance tasks and it is not feasible to assess them all. Instead, tasks that were critical to the safety of the train, or potentially posed a risk to the user, e.g. due to frequency or task duration, were prioritised for ergonomics analysis.

The design of complex systems involves many stakeholders and contractual relationships with grey areas where HF risk can hide. A train is a combination of hundreds of sub-systems provided by, often small, suppliers with limited engineering resource and little knowledge of HF. Some will opt to remain non-compliant with HF requirements or rely on the OEM's team to conduct the HF assessments on their behalf, for example during first article inspection (FAI).

The integration of the sub-systems into the train design is the responsibility of the OEM; this requires available computer aided design (CAD) data of each sub-system which is sometimes not available until detailed design phase when opportunities for design changes are limited. However, this is the point that many hazards, such as finger traps, trip hazards and insufficient visibility, become apparent.

Once the train is delivered, feedback loops to improve future designs would support continual improvement. Contractual boundaries between the organisations involved make these feedback loops difficult to create and maintain, but independent groups such as RDG could support this.

Established Designs: Ergonomics Assessment Maintenance Tool

On two other projects, a different approach was required. In the first the Ergonomics Integration Plan, produced during the bid phase, promised that many standard methods would be used to assess the design. In the second, the HF assessment was not requested until the train was built. The first led to the development of a credible ergonomic assessment tool which integrated the specified methods, as well as other mechanisms such as expert assessment to fill any gaps between approaches. This ergonomics assessment maintenance tool was applied to both projects.

The methods integrated into the tool included:

1. Postural assessment methods:
 - a. Rapid Upper Limb Assessment (RULA) (The Ergonomics Center, 2020)
 - b. Rapid Entire Body Assessment (REBA) (Ergonomics Plus, 2000)
 - c. Ovako Working Posture Analysing System (OWAS) (Karhu, Kansil, & Kuorinka, 1974)
2. Manual handling assessment methods:
 - a. National Institute for Occupational Safety and Health (NIOSH) Lifting Equation (The Ergonomics Center, 1994)
 - b. Health and Safety Executive (HSE) Manual Handling Assessment Chart (MAC) (HSE, 2018).
 - c. HSE Risk Assessment of Pushing and Pulling tool (RAPP) (HSE, 2016).
3. An expert review from qualified ergonomists utilising good practise for:
 - a. Poka-Yoke (American Society for Quality (ASQ), 2021)
 - b. Muscle Fatigue Assessment (MFA) (Rodgers, 2006)
 - c. Human Error Analysis (HEA) (Chemical Process Industries (CPI), 2019)
4. Ergonomics for the Prevention of Musculoskeletal Disorders (Swedish Work Environment Authority (SWEA), 2012).

The Design for Maintenance Engineer identified those tasks that were critical to the safety of the train, or potentially posed a risk to the user, e.g. due to frequency or task duration. These tasks were prioritised for ergonomics analysis.

The analysis was carried out using (1) CAD drawings of 5th and 95th percentile mannequins in the appropriate part of train, (2) Video footage of different user representatives, and (3) Technical documentation provided by the OEM. The tasks were analysed using the appropriate methods within the tool, which provided a clear pass or To be Determined (TBD) score (where additional evidence was needed); and the findings summarised in a dashboard. Issues identified during the analysis were recorded in the Ergonomics Issues Log for managing to close by engineering.

The process is summarised in Figure 3.

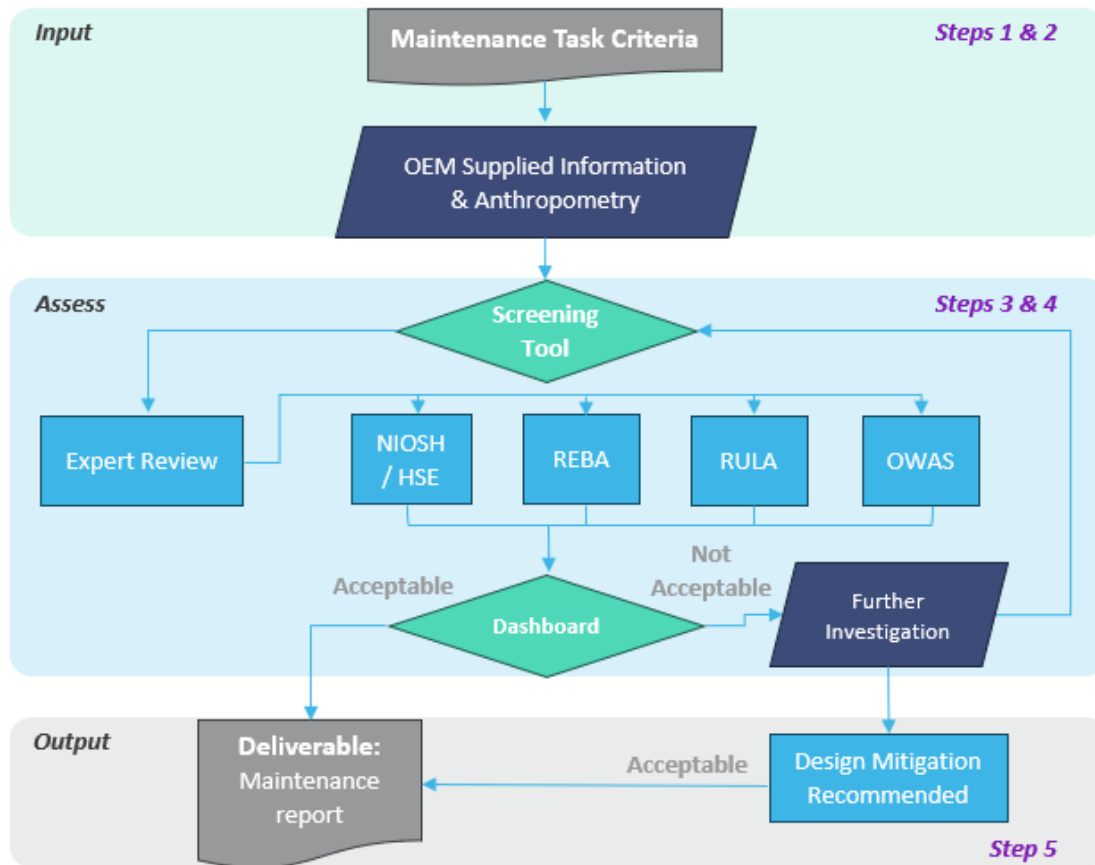


Figure 3: Ergonomics Assessment Maintenance Tool

In the first project when the tool was applied to the preliminary design review (PDR) phase, it was possible to gain customer acceptance to the method before application and, as a result, the HF assurance was accepted. In the second project, the customer refused to accept the work – although the application and results were sound, there were embedded political issues in the project that prevented acceptance. As a result, this remains a contractual issue, outside the scope of HF. This highlights the importance of early engagement between HF and project stakeholders.

Modification Programmes: Flexible and User Focused

Throughout the lifecycle of a train, upgrades and modifications are not necessarily applied consistently across the fleet. There are many reasons for this including obsolescence of available parts, or modifications being carried out in isolation of an engineering programme. With new builds, a HF assessment on one train is representative of the fleet. The same is not guaranteed for older fleets but the budget is never available to assess every vehicle individually.

In these cases, it is critical to engage maintainers who know the fleet in design reviews and prototype testing. These experienced maintainers will have developed their own ways of carrying out tasks and even have their preferred tools. Practical insight and experience are instrumental in confirming that tasks are achievable, even where this may not fully align with HF best practice. At the same time, the HF Specialist must use appropriate judgement to identify and question overly confident or “macho” attitudes, to ensure that potential hazards and risks are identified and mitigated.

As with new builds, it is more effective to prioritise assessments of tasks that present the greatest risk to maintainers or train safety and reliability.

Learning Points

Where budgets are limited, the following HF activities should be prioritised.

1. **Stakeholder engagement:** Early integration and alignment between engineering, customer, maintenance and operational stakeholders is essential. Critically, a HF champion who represents the maintenance organisation should be involved in the progressive acceptance of the HF methods and technical outputs.
2. **HF methods** can vary but should include:
 - a. Definition of clear design guidance that can be implemented by non-HF Specialists, e.g. integration engineers and system suppliers.
 - b. Prioritisation of the tasks to be assessed based on risk to gain maximum benefit from the available budget.
 - c. User engagement, in particular with experienced maintainers, during design reviews and validation testing.
3. **HF Design for Maintenance guidance and requirements** at an industry level would benefit all parties, e.g. a basic HFI process, a mechanism for prioritising maintenance tasks, and a consolidation of good practice from published texts. The target users would be procurement (to provide a reference in contracts), the customer as a checklist for acceptance, programme managers to understand the expectations, and HF Specialist for developing their HFI plans. A more robust approach would be requirements specified in industry standards.

Depot Design

Complex Environments

The challenge with integrating HF into depot design is the complexity of the environments, job roles, equipment and logistics. First, there are the different types of maintenance depot, ranging from stabling, servicing and cleaning to light and heavy maintenance facilities. Second, there are different depot types such as fleet maintenance depots and freight terminals (illustrated in Figure 4).



Figure 4: Types of Train Depots in the UK

More modern fleets may be maintained in a dedicated fleet maintenance depot which is built for a specific fleet and combines all functions in one location. In other instances, different types of maintenance tasks, e.g. servicing and cleaning, light maintenance and heavy maintenance, are carried out at different locations. As with vehicles, the age and state of the depots vary depending on the modifications that have occurred throughout the life of the facility.

For modern fleet maintenance the range of dedicated functional areas within a depot can be extensive; Figure 5 illustrates one example.

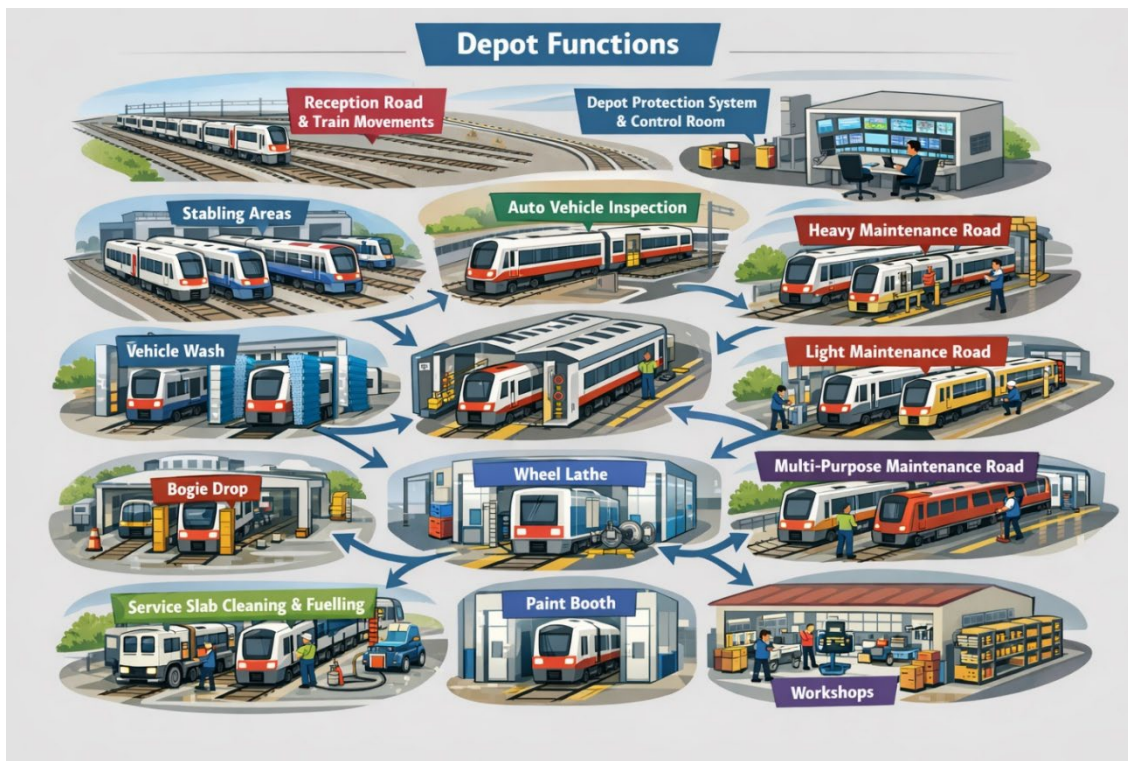


Figure 5: Functions within a fleet maintenance depot

Adding to the quantity of HF analysis required are the number of different users, tasks, equipment, and environmental factors in each functional area, as well as the tasks and equipment of more generic users of the depot such as train drivers and logistics staff.

Golightly et al. (2024) outlines the difficulties of designing train preparation yards for freight operations. The authors cite challenges with usability of equipment, yard conditions (lighting, walking routes), wagon conditions, time pressures and the organisation of work - particularly where third parties are involved. All of these challenges can contribute to human performance issues. The design of the depot and the operational controls (discussed later) are often specified and managed by separate organisations, which increases the importance of stakeholder engagement to prevent conflicts.

Commitment, Budget and Time

Budget and time constraints pose challenges on any project. However, if there is limited desire or commitment to implement HF, particularly from the customer – the likelihood of success is low. This is illustrated through two brief case studies.

A new rolling stock programme included delivery of a new fleet depot; both the rolling stock and depot contracts contained HF requirements. Rolling stock compliance was addressed in a consistent

and detailed manner by both the OEM and the customer, with sufficient time and budget allocated. In contrast, the HF team for the depot received very little budget and time. The programme was led by civil engineers with limited familiarity with HF, who did not recognise its value, and there was no pressure from the customer to demonstrate compliance. HF input was sporadic and the depot was accepted without compliance.

In a separate, ongoing, depot programme, HF input is defined by stringent requirements from the customer. The HF specialists are welcomed by the civil engineers but the mechanisms for HF integration on the programme are slow to merge. With a limited budget, HF activities have been deferred until the detailed design phase. However, the customer's HF specialist has acted as the champion for HF and raised awareness of its importance with the civil engineers. Collaboration is key to successful HF integration across the programme and delivery of a compliant product.

The preliminary challenge in both cases is that the projects are led by civils contractors who often have little or no experience of HF. Whilst budget and time are contributing factors to the successful integration of HF, if there is no customer demanding progress reports and compliance evidence, HF integration is unlikely to be a success.

Thorne and Smith (2023) share the importance of close working relationships between stakeholders. The High Speed 2 (HS2) programme benefits from an in-house HF team who works collaboratively with their external HF team(s), and the HF activities are underpinned by an organisational strategy that focusses on people: "Functional Efficiency: Design for Operational Excellence" and "People-Centred: Safety, inclusive and welcoming". This support from the top of the organisation, makes the integration of HF much easier to achieve.

Learning Points

The successful integration of HF into new depots requires four elements:

1. **Stakeholder Champion:** An end client with a HF lead or champion to hold the programme accountable for delivery, and an organisational strategy that acknowledges the importance of humans in the delivery of their services.
2. **Requirements:** Clearly defined contractual requirements; this is often achieved by referring out to a single guidance document or standard. At an industry level HF requirements could be integrated into the guidance documents produced by RDG (2021 and 2025). This could also reference out to relevant standards such as GIGN7621 (RSSB, 2018) Guidance for the Development and Design Considerations of Passenger Rolling Stock Depots, ISO 9241 (ISO, n.d.) Ergonomics of Human System Interactions, ISO 11064 (ISO, 2000-2013) Ergonomic Design of Control Centres.
3. **Time and budget:** More robust HF requirements would increase the likelihood that sufficient time and budget are allocated to sustain HF activities throughout the project lifecycle.

Depot Operations

The design of the train and the depot can be optimised through careful HF integration, but these benefits can be lost in the operation of the depot if not managed correctly.

European Union (EU) Directives (e.g., 2016/798) and Regulations (e.g., 2018/762) mandate the integration of human and organisational factors (HOF) into rail safety management systems and risk assessments. Such standards do not exist in the UK rail industry. As such, the only incentive for addressing HF risks in depot operations is the reduction of costs associated with lost time working, delays returning train to service or costs associated with trains failing in service.

Musculoskeletal Injuries – a problem or a symptom?

This case study comes from an investigation of musculoskeletal injuries in a passenger train maintenance depot. The original question asked was “why are staff injuries increasing?”. The expected output by the customer was training for front line staff, however the causal factors identified were not related to the design of the train or the actions of the staff. The output of the investigation differed from the original customer assumption, and the primary findings are summarised here.

Three methods were employed to enable the causal factors to be identified:

1. Analysing the injury data from the depot and reviewing incident investigation reports.
2. Site visits to observe tasks during day and night shifts.
3. Workshops with a range of internal stakeholders, from frontline maintenance staff to managers.

Incident Management

Incidents were insufficiently investigated and did not fully consider the RSSB incident factors detailed in RIS-3119-TOM (RSSB, 2023). Categorisation of injuries and causes was inconsistent or incomplete, and most incidents were not investigated at all beyond recording that the employee having hurt themselves. Similarly, when errors occurred, the organisational response would often focus on the affected individuals’ actions, rather than learning and preventing recurrence in the wider workforce.

The depot organisation is made up of employees and contractors. Injury and incident data is managed differently for the two groups. Staff and contractors also had different attitudes towards health and safety. A trend was discovered whereby incident reports among employees tended to peak after the fourth hour of a shift, coinciding with when they were able to go home (due to injury) while retaining full pay for the day. Meanwhile contractors appeared to be less likely to report minor injuries or injuries that did not require time off to recover; the reasons for this were not clear.

Management and Staff Relationships

A recurring theme during the workshops was a perceived disconnect between management decision-making and frontline operational realities.

Maintenance staff perceived that issues that were not seen by the public were not prioritised. One example cited was that reports of poor housekeeping conditions remained unresolved for several months and were addressed only shortly before a scheduled visit by a local dignitary and accompanying media representatives.

In another example, several workplace changes were implemented without prior consultation with depot staff. In one instance, raised platforms were procured to improve access during maintenance activities. However, user requirements and task context were not fully considered, and the platforms were not rated to support the combined weight of a technician wearing PPE and carrying tools.

More generally, shift production managers can be heavily occupied with planning and re-planning maintenance activities, limiting time available to observe work on the shop floor, identify emerging issues, and reinforce standards. As a result, maintenance staff frequently resolved operational challenges independently, with adaptations and workarounds embedded in routine practice.

Outcome

The review identified a significant gap between management assumptions and frontline operational realities, contributing to reduced confidence in reporting processes and the normalisation of local

workarounds. Limited organisational awareness of systemic contributory factors led to a focus on individual responses rather than underlying conditions.

As many causal factors were outside the control of the frontline staff, the primary intervention was a training programme that targeted leadership understanding of human error and the importance of human-based organisational factors in its mitigation.

User engagement in Depot Upgrade Planning

The HF team were engaged by Pendyne's Strategic Consultancy specialists, to plan and run stakeholder workshops. The purpose was to identify issues with the current depot design and propose solutions, to inform a depot upgrade strategy.

Task analysis is a standard tool in most design projects or operational assessments. However, these can be difficult to structure for complex scenarios involving multiple actors. Day In The Life Of (DITLO) scenarios are a flexible way of capturing who is doing what, where, how and with what equipment, captured in operational sequence diagrams. It enables tasks in their wider context to be understood and agreed with all stakeholders and then assessed, for example in terms of HF risks (physical and cognitive). The authors have utilised this method on many projects and Thorne and Smith (2023) describe its use on the HS2 depot programme.

In this case study, DITLO was used to structure the stakeholder workshops. The DITLO was developed from the VMIs and depot instructional documentation. The scenarios acted as a prompt to the stakeholders to explain what worked well and what could be improved. The purpose of the DITLO was to identify physical improvements to the depot but, interestingly, there were more extensive discussions on the organisational challenges.

Although organisational challenges were outside of the scope of the project and this was clearly communicated at the beginning of the workshops, discussions repeatedly returned to organisational issues. From a HF perspective they provided useful insights. On a positive note, maintenance operations demonstrated strong teamwork, clear roles, and effective communication, with teams able to respond flexibly to changing demands. However, less favourable were highly reactive planning limiting long-term visibility, and insufficient impact assessment of operational changes which were seen to reduce efficiency and increase risk. Greater engagement with frontline staff and more systematic use of performance and incident data were seen as essential.

Learning Points

Depot organisations are beginning to acknowledge the impact of HF-related organisational factors such as equipment design, policies and procedures, resource allocation, planning and workplace culture. However, the implementation is maturing slowly. Human error, like culture, is seen as intangible, difficult to manage and expensive. The following learning points emerged:

1. **Requirements:** The integration of HF organisational requirements into safety management standards (and ideally legislation) would increase the utilisation of good practice in depot operations that is consistent and sustained. One option is to utilise the HF incident factors (RSSB, 2023) for prevention, guiding leaders towards practical solutions to mitigate risks.
2. **Guidance and Education:** There is a need across the industry to raise awareness of, and build confidence in HF, particularly around human error. The link between HF risks, failure in service and associated delay costs needs to be made more visible and promoted extensively. Awareness raising campaigns should be accompanied by easy to implement solutions that are tangible and meaningful to depot leaders and managers.

3. **Investigation:** More robust use of the HF incident factors (RSSB, 2023) in incident investigation is required, to enable better quality of data to be collected to inform appropriate change and continual improvement.
4. **Stakeholder Engagement:** As with end user engagement in train and depot design, it is critical for organisations to engage with their front-line staff to understand the day-to-day challenges, engage staff in developing solutions, and utilise feedback loops to assess efficacy of the solution.

Discussion

The management of HF risks in vehicle maintenance and depot environments is a complex “system of systems” challenge. To optimise train maintenance and reliability—while reducing the costs associated with failures and delays—the industry must address the approach of HF in three interdependent elements: train design, depot design, and depot operations.

The authors’ review of their experience has identified topics that are common to all depot environments and that can contribute to the reduction of HF risk. They are summarised in Figure 6 and described in more detail below.



Figure 6: Key Learning Topics

1. **Stakeholder engagement:** HF activities are always collaborative, and the engagement of stakeholders is critical to success. At an industry level, there needs to be greater awareness of the financial benefits of HF in design and operations, particularly in customer, operational and civils organisations. At project level the HFI programme should identify the stakeholder organisations and their HF lead or champion, as well as organisations who have a direct impact on HF risk, e.g. sub-system suppliers, integration engineers. The HFI programme should include “value add” activities, e.g. requirements definition, joint design reviews. At an industry level, stakeholder buy-in could be achieved through groups such as the DWG, RDG and NFSG. And within organisations, improved engagement between

leadership and front-line staff, with effective feedback loops will support pro-active risk reduction.

2. **HF Guidance and Requirements:** There is a need for clearer, more accessible guidance to enable HF good practice to be readily integrated into design and operational programmes, which are applicable to all stakeholders. This could be developed by the HF lead at project level, or at an industry level through the RDG depot publications (2021, 2025) and Key Train Requirements (2023), or mandatory standards. Similarly, the introduction of mandatory HF requirements into safety management standards would encourage pro-active management of human error and improve the quality of incident investigations, analysable data and continual improvement cycles.
3. **HF Methods:** With limited budgets, it is necessary to use methods that have the greatest impact. DITLO should be used to describe complex scenarios, with desktop analysis building on the DITLO to assess and de-risk critical tasks. This should be supplemented with the knowledge of experienced maintainers in reviews, inspections, validation testing and feedback loops. This is equally applicable to train design, depot design and depot operations.
4. **Investigation and Feedback Loops:** The implementation of the HF incident factors (RSSB, 2023) during incident investigations and the quality of the data output requires improvement if the industry is to learn and reduce the number of occurrences. Ideally, feedback loops would exist to enable feedback between train design, depot design and operations – RDG / DWG / NFSG and their deliverables could facilitate these loops.

Conclusion

The aim of this paper has been to consolidate the authors' experiences and knowledge of depots and train maintenance with that of other published authors. Our purpose was to identify commonalities and to contribute to the mechanisms by which the rail industry can benefit from the application of HF to improve service reliability and reduce costs. While significant advances have been made to integrate HF in rolling stock and signalling design, the maintenance of broader rail infrastructure and rolling stock and the environments where these activities take place, have not yet received the same level of attention, perhaps because these tasks performed out of sight of the public eye. Poorly managed maintenance errors and safety risks lead to costs associated with in-service failures, lost working time in depots, injuries, and time taken to return trains to service.

HF offers tools, methods and insights that can make a valuable contribution in addressing these issues. While the context and the challenges are different, the aim of HF in this work remains unchanged: to improve safety, efficiency, productivity, human wellbeing and health. At this time, this is best achieved by four main activities: (1) Stakeholder engagement including awareness raising (2) Published HF guidance and robust HF requirements in industry standards (3) Prioritising HF methods (based on likely scope, time and budget) to maximise impact, and (4) Improving the HF elements of incident investigations and developing design feedback loops to enable continual improvement.

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