

Guidance Document

G0189

Adhesion Management for Open Sections of the LU Network

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1 Purpose

- 1.1 The purpose of this Guidance is to be a reference document for work to implement new or expand/modify an existing Adhesion Management System (AMS). It covers:
- a) A process and guidelines for determining AMS strategy and requirements, AMS selection and embedding the system into business-as-usual use,
 - b) Explanation of the reasoning for the technical content of the Category 1 Standard (S1189).

2 Scope

- 2.1 This Guidance primarily applies to Adhesion Management Systems for lines operated in ATO. It can also be used for lines where the trains are driven manually. It is therefore applicable to all of the following:-
- Definition, development, specification and implementation of the required Adhesion Management system to enable the introduction of ATO on any open section of the LU network
 - E.g. As part of a Line Upgrade lines when first implementing ATO
 - Review, modification or enhancement of an existing AMS when
 - Relevant assets are changed or significantly modified (e.g. new signalling, ATC or RS)
 - A significant change is made to the line characteristics (e.g. extensive vegetation work, enhanced timetable)
 - The review, development, modification or enhancement of an existing Adhesion Management system due to unsatisfactory performance on a line. "Unsatisfactory performance" could mean:-
 - An unacceptably high number of overruns in service
 - One or more unacceptably long overruns in service
 - An unacceptably high level of wheel damage (wheel flats or pitting)
 - An unacceptably high level of rail damage
- 2.2 The aim of this guidance is to outline a consistent and integrated approach to Adhesion Management Systems in London Underground.
- 2.3 This guidance document explains the reasoning behind the requirements mandated by the Category 1 "Variable Adhesion Conditions - Requirements for the Implementation of ATO on any Open Sections of the LU Network" Standard (S1189) and offers guidance on the best practice approach for achieving compliance with this Standard.

- 2.4 The guidance document also explains, where relevant, the current strategic approach to Adhesion Management in London Underground (as at the date of issue of this document). Note this document is planned for review two years after the issue date in recognition of the need to incorporate experience gained from the Adhesion Management Systems implemented or which will be implemented in the near future to enable the implementation of ATO on additional open sections.
- 2.5 Sections of the AMS Category 1 Standard (S1189) are quoted in appropriate sections within this guidance document. Clauses from the Standard are shown as text in italic within a box, for example:

<i>S1189 Section 3.5.2</i>	<i>Data Access</i>
<i>TfL shall be able to access and interpret all input and output data in a documented readable format</i>	

3 Guidance

3.1 Adhesion Levels and Conditions

- 3.1.1 The following table provides guidance on the range of adhesion levels that may be experienced under a variety of ambient conditions

Site Categorisation	Conditions	Typical Range of Adhesion
Open but not leaf fall vulnerable	Snow and Ice Mist, fog, dew, drizzle, onset of light rain Sustained slight or light rain Sustained moderate or heavy rain Dry, clean rail	0.02 – 0.06 0.05 – 0.08 0.08 – 0.12 0.12- 0.16 > 0.16
Open and leaf fall vulnerable	Damp, leaf fall contaminated rails Snow and Ice Mist, fog, dew, drizzle, onset of light rain Sustained slight or light rain Sustained moderate or heavy rain Dry, clean rail	0.02 – 0.06 0.02 – 0.06 0.05 – 0.08 0.08 – 0.12 0.12- 0.16 > 0.16
Tunnel or covered	Rail with excessive lubricant Dry, clean rail	0.05 – 0.1 > 0.16

The following terms are used to describe the relevant adhesion category and adhesion level.

Adhesion Category	Adhesion Description	Adhesion Level
Dry Rail	Good	≥ 0.2
Steady Rain	Sufficient	0.12 – 0.2
	Adequate	0.10 – 0.12
Degraded	Marginal	0.08 – 0.10
	Poor	0.06 – 0.08
	Low	0.04 – 0.06
	Exceptionally Low	≤ 0.04
Compromised	Any level of adhesion which is not high enough to avoid wheelspin (in motoring) or wheelslip/slide (in braking) for the applied level of acceleration or braking	

- 3.1.2 The seven Adhesion Descriptions are used within the “Estimated Adhesion Level” logic in the Condition Assessment Software.

For ease of use, these seven adhesion descriptions have been grouped into three adhesion categories – “dry rail”, “steady rain” and “degraded”. The “steady rain” category reflects “steady state” conditions, under varying levels of sustained rainfall, with moderate and heavier rain producing better adhesion than slight or light rain.

- 3.1.3 The “degraded” band covers both transitional conditions – e.g. the onset of light rain on clean rail – which may last for just a few minutes and the range of adhesion levels which can occur under contaminated rail/damp conditions - which are primarily related to leaf contamination of the railhead during the Autumn. The adhesion resulting from the “wrong combination” of railhead leaf contamination, a high level of leaf mobility and low levels of moisture and precipitation can fall to the “low” or even “exceptionally low” level, although the effect of mitigation will normally limit the adhesion to either “marginal” or “poor” during the leaf fall season.
- 3.1.4 Unusual or extreme conditions can also cause the adhesion to fall to the “exceptionally low” level. One example of this is heavy rain causing a “carpet of leaves” to fall onto the rails from overhanging vegetation. If a train then runs over the fallen leaves, this will result in the sudden creation - on the railhead - of a heavy level of damp/wet leaf contamination and thus an “exceptionally low” level of adhesion.
- 3.1.5 The term “compromised” is used to identify any level of adhesion which is not high enough to avoid wheelspin (in motoring) or wheelslip/slide (in braking). Depending on the applied level of acceleration or braking, the level of adhesion at which spin or slip/slide occurs may be anywhere between “sufficient” and “exceptionally low”. For example, a high rate of acceleration on a train, particularly one with less than 100% wheelsets powered, can provoke spin under adhesion defined as “sufficient” while on “low” or “exceptionally low” adhesion, reduced levels of acceleration or braking may still provoke sustained spin or slip/slide.

3.2 Adhesion Management System

3.2.1 The following sections provide guidance regarding:-

- The definition of the Adhesion Management System requirement
- The determination of the drivers for implementing Adhesion Management
- System selection
- Identifying research & development requirements
- Embedding the system into business-as-usual use

3.3 System Development & Delivery Process

3.3.1 The process outlined within this section is applicable at many levels of detail. It can be applied to perform a high level analysis of Adhesion Management requirements across the LU/TfL network, through to development and delivery of discrete adhesion management system solutions.

This guide is intended to be followed within existing best practice project delivery process.

There may be scope to modify the precise requirements for project delivery, since the LU AMS Strategy is for any new AMS to use proven and accepted systems and products – such as the Condition Assessment Software (CAS) – which are already in use on existing Adhesion Management Systems.

A core principle of this Guidance Document and the AMS Standard is that the Adhesion Management System and assets should not be treated differently to other assets; projects are required to follow all governance steps for the delivery of AMS including asset documentation, training, handover and entry onto the appropriate Maintenance Management System as a maintainable asset.

Error! Reference source not found. below, which is based upon the process contained in ISO 17359:2011, Condition monitoring and diagnostics of machines -- General guidelines, outlines the recommended process to follow for developing and introducing any new low adhesion management system:

1. Strategy Definition

Definition of the line/route specific Adhesion Management strategy. Ensure alignment and

consistency with the overall LU Adhesion Management Strategy

2. AMS Benefit-Cost Prioritisation Analysis

Identify and quantify the potential service performance benefits (increments) and the costs (initial and on-going) of the required adhesion management measures to enable each performance benefit increment to be attained

3. Define Success and Failure Criteria

Produce an initial statement of the success and failure criteria to be applied to the Adhesion Management System (AMS)

4. Review of Existing Systems

Review the Adhesion Management systems already in use, particularly on LU, and identify (i) any aspects of those systems which require enhancement or development for the proposed new system and (ii) additional features which would be required to meet the defined success and failure criteria: identified items to be included in R&D scope

5. Assessment of Service Reliability and Criticality

Assess the potential consequences of AMS failure modes and the likely impact on service operation and maintenance activities and costs: ensure AMS measures are provided to address all significant risks: any new capability to be included in R&D scope

6. Research and Development

Conduct of feasibility studies, trials and development of required AMS enhancements

7. Adhesion Management Project Delivery

Business case, funding, scope, design, contracts, installation, commissioning, update maintenance regime and processes, handover

8. Embed Business Change

Ensure the required processes and maintenance regime for the Adhesion Management System are followed. Ensure service performance achieved delivers targeted benefits. Deliver any required organisational change to ensure the AMS continues to be implemented, developed and maintained.

Figure 1 - Recommended Process for the delivery of Adhesion Management Systems

3.3.2

Applying this process ensures consistency to the way in which Adhesion Management Systems are developed, that the optimum AMS configuration is selected, that only AMS measures which are demonstrably cost-effective are progressed and that the potential benefits of the AMS are actually delivered – both initially and are then sustained in live operation

The AMS solution should be designed and optimised to:

- a) Define the service requirement*
- b) Determine the likelihood of adhesion related issues*
- c) Determine the required control measures*
- d) Determine the required mitigation measures*
- e) Optimise the AMS*

The sub-sections below offer explanation and guidance for each process step.

3.3.3 Strategy Definition

The strategy for AMS should be defined at several levels

- The High-Level (LU Network) Adhesion Management Strategy
- The AMS Strategy captured in Asset Group Strategies (AGSs) and Asset Maintenance Plans (AMPs)
- An application (line or route) specific or project specific Adhesion Management System Strategy for compromised adhesion conditions covering the strategy, aims and objectives for applying adhesion management system to a line or route for the first time or updating or modifying an existing adhesion management system. This should be linked with the defined service requirement and the success and failure criteria developed for the AMS.

As relevant to the work being carried out, the relevant parent documents should be reviewed to ensure the Adhesion Management solution delivered is consistent with these strategies and plans

3.3.4 AMS Benefit-Cost Prioritisation Analysis

- 3.3.4.1 For a line or route which is to be operated in ATO, there is a requirement (defined in the Cat 1 Standard S1189) to implement predictive adhesion management. The extent and scope of the adhesion management measures required for a particular line or route will be determined from the analysis of its current and future operational modes, the targeted service performance, the line characteristics, the current and projected levels of asset damage and the costs of the adhesion management measures needed.
- 3.3.4.2 Performing a prioritisation analysis should establish the key business drivers affecting a particular line or route. These can then be used in determining the extent of the Compromised Adhesion Management measures that need to be applied and in defining the success criteria for an effective solution.

For example, a line may be operating in ATO but is unable to deliver the service targeted because of :-

- (i) the time required to implement changes to the acceleration/service brake rates;
- (ii) the level of wheel damage being sustained
- (iii) the extent of the rail damage being sustained
- (iv) the leaf fall mitigation trains are unreliable

The improvements required, and the cost of these changes, can be assessed against the benefits that would be derived if the targeted service performance was delivered and the asset damage was reduced.

- 3.3.4.3 Even for the simplest type of operation (manually driven trains), compromised adhesion management issues need to be considered (even if they may not have been recognised as such). For example:-

- train operators will need to be trained in the most appropriate method of driving for various weather conditions (professional/defensive driving) and assessed for their ability to implement these techniques
- the design of the motoring and service brake controls needs to be such as to enable these driving techniques to be applied in practice – e.g. how graduable are they?
- whether WSP is to be installed on the trains and the effectiveness of the WSP system selected
- whether motoring wheelspin control is to be installed on the trains and its effectiveness in controlling the spin and avoiding rail damage when spin correction occurs

- the selection of an emergency brake rate for the calculation of signal overlaps or safety distances and the underlying assumption regarding the level of available adhesion
- whether train borne sanders are to be installed on the trains

3.3.4.4 As service requirements increase, e.g. through the introduction of enhanced timetables or automatic train control and operation, the extent of the required adhesion management assessment and mitigation measures becomes both more extensive and more critical.

3.3.4.5 The entire suite of measures implemented (people, process and tools) for both adhesion prediction and mitigation comprises the low Adhesion Management System.

3.3.4.6 An enhanced required train service (e.g. increased trains per hour or reduced journey times) will be reliant on improved train performance (e.g. increased levels of motoring and braking demand) and hence increased levels of adhesion to support those demands. In consequence, the adhesion management measures required to support those adhesion demands will need to become increasing extensive and comprehensive and the delivery of those measures will be increasingly critical to the reliable and cost effective operation of the service.

For example:-

Consider a line which currently operates with a normal ATO brake and a reduced ATO brake rate for use under adverse conditions; suppose it is decided that, to improve the service, the line is required to operate at the normal ATO brake rate at **all times**

The implications of this is that the braking performance of the train will need to be improved so that the normal ATO brake rate can be achieved under any combination of circumstances – e.g. prevailing weather, adhesion level, initial speed,

This might require the fitment of train borne sanders (probably multiple installations along each train) with associated depot facilities for their maintenance and re-filling and might also need additional equipment to provide an increased level of local site condition information (e.g. moisture and rainfall detection at every station or on every train might be required).

A similar set of requirements might emerge if it was proposed to increase the normal ATO brake rate (e.g. from 0.75 m/s^2 to 0.9 m/s^2).

Both of these would necessitate a review of the “headroom” (separation) between the AO brake rate and ATP brake rate. This needs to be sufficient to enable the ATO to regain the ATO brake profile without breaching the ATP/MSS curve and invoking an emergency brake application.

As a further example, consider the issue of rail squat formation which can occur during acceleration. This risk is most prevalent at relatively low speeds – 15 to 30 kph (when the tractive effort is high) - on trains fitted with electronic wheelspin control utilising creep control.

Unless appropriate measures are included to minimise the risk of this problem, the introduction of ATO with its higher targeted performance can result in a significant increase in the scale of this problem. Possible mitigating measures which can assist in this include:-

- (i) Wheelspin control which does not incorporate creep control or with a reduced level of creep
- (ii) Reduced acceleration rate when re-accelerating between stations
- (iii) Regular railhead treatment (e.g. grinding on a “little and often” basis) to remove any defects
- (iv) On train detection of ambient conditions and automatic adjustment of the applied tractive effort

3.3.4.7 Factors worth considering when performing an analysis of the required Adhesion Management measures which need to be included within the AMS are:

- Customer dis benefit if the targeted service is not delivered

- Cost of incidents: both direct (Lost Customer Hours, service disruption) and indirect (subsequent investigations, possible regulator involvement, possible retrospective implementation of additional measures and modifications), reputational cost
- Cost of failures: Lost Customer Hours, asset damage replacement & repair cost, consequential damage, equipment life degradation, reputational cost.
- Asset population & variability: implementation of a generic solution across multiple lines; more applications→ sharing of core costs, application differences handled through configuration, benefit of cross line AMS information and coverage
- Cost of maintenance: cost of maintaining the various mitigation measures, including depot facilities (e.g. replenishment/re-filling)
- Opportunities: potential gain through shared data provision (e.g. weather data; weather stations) across both lines and seasons

3.3.5 Existing Adhesion Management Systems

- 3.3.5.1 When implementing Adhesion Management it should be more cost effective to use and cascade an existing system which provides the required functionality rather than develop a duplicate system. Cascading an existing solution delivers benefits in respect of consistency of approach and allowing all improvements to be applied to each instance at minimum cost.
- 3.3.5.2 The Adhesion Management Systems in use on LU lines have an Adhesion Prediction Capability (APC) provided by a generic Condition Assessment Software (CAS). This provides the adhesion predictions which enables pre-emptive action to minimise the risk of “compromised adhesion induced” service affecting incidents .
- 3.3.5.3 This generic CAS requires various data feeds to enable the adhesion predictions to be produced. The combination of the CAS and its various data feeds provides the APC for that line or route.
- 3.3.5.4 The APC is then supplemented by line specific mitigation measures to provide the overall Adhesion Management System for that line. The (overall) AMS will encompass aspects such as the ATC control facilities, the RS braking performance under compromised adhesion conditions, vegetation management, line side devices, mitigation trains etc.
- 3.3.5.5 The Adhesion Management experts in the engineering functions are best placed, in general, to provide information on the functionality of existing Adhesion Management Systems.

3.4 Methods of Adhesion Management

- 3.3.4.1 Table 1 shows some typical examples of AMS techniques which may be used on a particular line. As the service operation requirement increases, the scope of the adhesion management system and the extent of the adhesion management measures increase to enable the required service to be operated with the minimum risk of service disruption.

The following table (table 1) illustrates the possible variation in AMS.

ATO Route	Enhanced level of adhesion management (AMS Level 1)	Highest level of adhesion management (AMS Level 2)
Manually Driven Route	Base level of adhesion management (AMS Level 0)	Enhanced level of adhesion management (AMS Level 1)

	Non leaf fall vulnerable route or area	Leaf fall vulnerable route or area

Table 1 – Summary of the extent of adhesion management required for different types of route

- 3.3.4.2 Table 2 (below) provides examples of the AMS measures which may be used on a particular line depending on its operational mode (e.g manually driven or ATO). As the service operation requirement increases, the scope of the adhesion management system and the extent of the adhesion management measures increase to enable the required service to be operated with the minimum risk of service disruption.

Operational Mode	Adhesion Management Measures
Manually driven trains operating in a non leaf fall vulnerable area but exposed to a typical range of weather conditions including rain, snow, ice	Trains fitted with standard precautionary measures such as de-icing, sleet brushes and preferably with anti-icing, WSP and sanders Train operators required to use professional driving techniques to adjust driving style to prevailing conditions Cab simulators used to train and assess train operators' professional driving capabilities and conduct refresher training and assessments

Operational Mode	Adhesion Management Measures
Manually driven trains operating in a leaf fall vulnerable area (and exposed to a typical range of weather conditions including rain, snow, ice)	Trains fitted with standard precautionary measures such as de-icing, sleet brushes and preferably with anti-icing, WSP and sanders Train operators required to use professional driving techniques to adjust driving style to prevailing conditions Cab simulators used to train and assess train operators' professional driving capabilities and conduct refresher training and assessments Leaf fall mitigation trains provided to clean and treat railhead in leaf fall vulnerable zones Ongoing vegetation management and vegetation surveys Adhesion Prediction Capability (APC) provided to identify in advance when adverse conditions will exist and require the operation of the leaf fall mitigation trains Ongoing provision of line specific Condition Assessment Software (CAS) Ongoing provision of line specific leaf fall and weather forecasts to the adhesion prediction system Deployment of track side equipment to provide leaf fall mitigation at specific sites

	Deployment of track side equipment to provide site specific environmental data Autumn site inspection, leaf collection and removal (especially P&Cs) 24/7 Adhesion Controller for leaf fall season to manage day to day mitigation measures
Line operated in automatic mode in a non leaf fall vulnerable area but exposed to a typical range of weather conditions including rain, snow, ice	Trains fitted with standard precautionary measures such as de-icing, anti-icing, WSP and ideally sanders RS compromised adhesion brake performance consistent with the ATO brake rates and the possible range of adhesion conditions Adhesion Prediction Capability (APC) provided to identify in advance when adverse conditions will exist and require the ATO brake rate to be changed Ongoing provision of line specific Condition Assessment Software (CAS) Ongoing provision of line specific leaf fall and weather forecasts to the adhesion prediction system Deployment of track side equipment to provide site specific environmental data Real time feedback of data from the RS concerning the operation of the WSP and sanders Real time feedback from ATO concerning the currently applied ATO brake rate at each site 24/7 Adhesion Controller to manage day to day mitigation measures throughout the year Routine railhead re-profiling undertaken
Line operated in automatic mode in a leaf fall vulnerable area (and exposed to typical range of weather conditions including rain, snow, ice)	Trains fitted with standard precautionary measures such as de-icing, anti-icing, WSP and ideally sanders RS compromised adhesion brake performance consistent with the ATO brake rates and the possible range of adhesion conditions Adhesion Prediction Capability (APC) provided to identify in advance when adverse conditions will exist and require the ATO brake rate to be changed and the leaf fall mitigation trains to be operated Ongoing provision of line specific Condition Assessment Software (CAS) Ongoing provision of line specific leaf fall and weather forecasts to the adhesion prediction system Leaf fall mitigation trains provided to clean and treat railhead in leaf fall vulnerable zones Ongoing vegetation management and vegetation surveys

	Deployment of track side equipment to provide site specific environmental data Real time feedback of data from the RS concerning the operation of the WSP and sanders Real time feedback from ATO concerning the currently applied ATO brake rate at each site Autumn site inspection, leaf collection and removal (especially P&Cs) 24/7 Adhesion Controller for leaf fall season to manage day to day mitigation measures Routine railhead re-profiling undertaken
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Table 2 (above) - Typical adhesion management measures for different types of route

3.5 AMS Scope

The scope of an Adhesion Management System will be critically affected by the following issues:-

- What is driving the need to either implement AMS on a line or to review, modify, upgrade or expand an existing AMS on a line? E.g. (Note that several of these may apply)
 - Unacceptable performance, during part or all of the year, in respect of:-
 - Number of compromised adhesion events (overruns, SPADs, EB interventions etc)
 - Amount of asset damage sustained (to either wheels or rails)
 - Regulatory intervention
 - Conversion of a line from manual operation to ATO
 - Usually part of a Line Upgrade project
 - Significant enhancement in the service to be operated
 - Increase in trains per hour
 - Increase in targeted motoring and braking rates
 - Increase in maximum permitted speed
 - Removal of existing mitigation measures, e.g.
 - Loss of a mitigation train
 - Removal of a speed restriction
 - Loss of site inspection resource
 - Loss of manual mitigation teams
 - Replacement of passenger rolling stock and/ or signalling/ATC system
 - Change to the passenger rolling stock's compromised adhesion brake performance (e.g. installation of train borne sanders)

- Change to the ATC control centre capability in respect of implementing motoring and braking rate changes
- Replacement or provision of leaf fall mitigation trains
- Inter-running issues
 - Introduction of inter-running
 - Modification to the “inter-running” rolling stock
 - Change in the (type of) “inter-running” rolling stock
 - Cessation of inter-running
- Significant changes to the route
 - Line extensions or diversions
 - Introduction of additional stations
 - Re-location of one or more stations
 - Topography changes

3.6 AMS Data Considerations

3.6.1 AMS Data Collection

- 3.6.1.1 AMS data should be logged continuously and subsequently retained so as to enable detailed analysis of any incidents which occur. This should be done via the CAS.
- 3.6.1.2 A key benefit of this approach, which is worth appreciating, is that of being able to establish when conditions were predicted to change and being able to compare this to the reported sequence of events. This provides an audit trail and enables a subsequent comparison between predicted and actual events.

3.6.2 AMS Data Measurement Feasibility

- 3.6.2.1 When considering the methodology for collecting adhesion management data, the feasibility of accessing the locations where measurements need to be taken should be taken into account. Wherever practical, this should be automatic and should avoid exposing members of staff to a significant safety risk. (One example is the use of track staff to capture data or apply mitigation which requires access to the track during traffic hours).
- 3.6.2.2 Data which may be being acquired for other purposes may be able to provide some of the information required by the AMS. Communication with condition monitoring systems and the use of data from those systems should be considered when determining the means of acquiring the required adhesion management data.

3.7 Research & Development

- 3.7.1 The extent to which R&D is required in connection with the implementation of Adhesion Management on a new line or route will depend in part on whether the AMS requirements are defined prior to the specification of the individual asset areas or whether (wrongly) the AMS has to be implemented retrospectively.
- 3.7.2 The potential areas of an AMS where R&D may be required are likely to be:-
 - The adaptation of the LU generic CAS to meet the specific requirements of a new line or new application and to optimise it accordingly
 - The provision, within the ATC control centre, of the ability to rapidly implement acceleration and service braking rate changes to pre-defined groups of sites

- This issue should be addressed as requirements within the ATC Specification
- The provision and appropriate use of hand held device to provide local, site specific data to the CAS
- The provision of ATC acceleration and braking rates consistent with the targeted service performance and the potential range of open section adhesion
 - If possible, do not specify rates higher than are necessary for the service
- The provision of the required brake performance on compromised and degraded adhesion conditions by the rolling stock
 - This issue should be addressed as requirements within the RS Specification
- The provision of appropriate wheel spin correction on the rolling stock to minimise the risk of squat like defect formation in the railhead
 - This issue should be addressed as requirements within the RS Specification but may require development and testing to define those requirements
- Appropriate means of detecting and reporting prevailing conditions (e.g. precipitation, railhead moisture, railhead contamination) to the CAS
- The interfacing of the CAS with the ATC (or Railway Control System) for data transfer (ATC/RCS to CAS) and for the communication of acceleration and service brake rate changes (CAS to ATC/RCS)
- The development of simulation facilities to enable the performance of rolling stock, on compromised and degraded adhesion conditions, to be modelled and improved
 - E.g. Whole train simulation and Dynamic/blended brake slip correction
- The application of mitigation from service trains without requiring any action by the train operator or impacting on the passenger carrying capability of the train
- The automatic implementation of required changes to ATO motoring and braking rates by the ATC in response to the CAS output

Upon completion of any Research and Development, it is important to document and share what has been learned so that this knowledge can be captured for future use.

3.8 Adhesion Management Project Delivery Steps

- 3.8.1 When delivering or implementing an Adhesion Management System as a project it is important to follow the current TfL/London Underground Project Process (Pathway) or equivalent best practice for business units which don't use Pathway. This section covers points of note which are additional to these existing best practice project delivery frameworks.
- 3.8.2 The project team should ensure that they have positively engaged with all relevant parts of the project (e.g. ATC, RS and Track), the TfL/LU Adhesion Management engineering experts, the appointed representative(s) of the maintainer, who will be required to maintain the AMS, and the relevant S&SD sponsor.
- 3.8.3 An Operational Concept for the line or route should be developed. This should incorporate the AMS to ensure that its critical role is appreciated, that its output will be used as intended and the benefits (maximised ATO, minimised low adhesion incidents and minimised asset damage) are delivered.
- 3.8.4 Given the way in which the ATO low adhesion management requirements for existing lines have been developed (i.e. after than in advance of ATC and RS specifications) it has, to date, inevitably meant that AMS has had to be implemented retrospectively. Unfortunately, this has meant the systems do not necessarily achieve their full potential because the system has not been

fully integrated with the end user's facilities and their processes. This approach has also resulted in greater cost than would otherwise have been the case

- 3.8.5 Training of end users in how to use the system and setting up a system of ongoing competence management (e.g. training, assessment, refresher courses) should be undertaken as a matter of best practice. However it is worthy of specific comment because this has been an area which has been an issue for some of London Underground's existing adhesion management systems.
- 3.8.6 Documentation of the system, so it can be maintained and supported by engineers, should be provided as part of project delivery best practice.
- 3.8.7 When a new Adhesion Management is implemented or an existing one is enhanced, it is important to ensure that the maintenance requirements, including ongoing budget provision, are addressed by embedding the system into "Business As Usual".
- 3.8.8 Steps which should be taken to ensure the AMS is aligned with delivering the service benefit targeted by a project include:
- Deliver a defined maintenance regime for all elements of the Adhesion Management System
 - Ensure there is a spares and service agreement, if necessary, for the AMS
 - AMS should be considered an asset and appropriate elements (e.g. line side equipment, mitigation trains) should therefore be entered into the CMMS (Ellipse for LU at present)
 - The maintainer & other personnel expected to use the system should be trained
 - The organisation structure should ensure the resources and budgets are provided to support, maintain and develop the Adhesion Management System on an on-going basis
 - Before completion of handover of the system, evidence of the above actions having been completed should be gathered and accepted by the maintenance representatives.
 - Evidence of the above actions having been completed should be required as part of the approval to implement ATO on any open section of the LU network.

3.9 Adhesion Management Technical Requirements

In this section, an explanation of the rationale for the technical requirements in S1189.

Guidance is provided for the requirements covered in Parts A, B, C and D of S1189.

3.9.1 Adhesion Management System Development

S1189 Section 3.1

Existing Adhesion Management system expansion and/or new AMS selection and design shall not commence without first consulting with the Technical Content Manager of this Standard.

Early consultation should be undertaken to avoid the risk of abortive work through failing to appreciate the extent and capability of existing Adhesion Management Systems.

This section provides guidance covering the requirements contained in Part A of S1189

3.9.2 Option Assessment

S1189 Part A Section 3.2

For any line which is to be operated in ATO, modelling shall be undertaken to assess the implications of different motoring and service braking rates, the resulting service capability and the mitigation measures required to avoid excessive asset damage, from compromised and degraded adhesion conditions whilst achieving the targeted service performance

The aim is to enable the targeted performance to be achieved but with commensurate mitigation - against compromised and degraded adhesion conditions - so as to minimise the risk of damage to either the track or rolling stock. As the targeted performance increases, the required mitigation measures should be enhanced accordingly with the costs of these measures being offset against the benefits derived from the enhanced performance.

3.9.2.1 Train Performance Definition

S1189 Part A Section 3.2.1

For any line which is to be operated in ATO, modelling shall be undertaken to assess the implications of using different motoring and service braking rates and the resulting impact on service capability.

The maximum adhesion levels have been derived from experience on Central and Jubilee Lines. The adhesion levels for motoring have been influenced by the issue of “squat like defects” formation. The investigations conducted to date indicate that a prime cause of these defects is the use of creep control within modern traction systems to correct wheelspin.

The re-acceleration of a train from a speed of around 20 kph, e.g. having been checked as a result of a train ahead, is the particular scenario when the correction of wheelspin is very likely to result in the formation of a squat like defect.

The imposition of the defined performance and adhesion limits will constrain the performance which could be achieved if good adhesion (dry rail) conditions are assumed. If the benefits of a higher (good adhesion) performance under compromised and degraded adhesion conditions are significant, then these benefits should be assessed against the cost of the additional adhesion management capability required and the maintenance costs arising from the use of an increased performance capability.

The use of open section adhesion limits, acceleration and braking rates higher than those defined in the Standard would require a concession against the Standard. This would require justification and the implementation of appropriate low adhesion management measures would provide a suitable justification for agreeing such a concession.

It is for consideration whether there is value in having three performance settings – “good conditions”, “variable conditions” and “degraded conditions”. For example, this approach could provide ATO acceleration and service braking rates as follows:-

	Good Conditions (Dry rail)	Variable Conditions	Degraded Conditions
Acceleration	Maximum Performance (~1.3 m/s/s)	70% performance (~0.9 m/s/s)	40% performance (~0.5 m/s/s)
Service Braking	0.75 m/s/s	0.75 m/s/s	0.45 m/s/s

The “good conditions” settings could be used under conditions of confirmed dry rail (or more widely if the capacity benefits outweigh the maintenance costs of addressing the rail damage arising from rail damage such as squat like defects). For “dry rail only” use, this would require the AMS to be provided with sufficient data to be certain of the railhead condition and would be likely to need additional monitoring and detection capability. The cost of obtaining and providing this data would need to be offset against the potential capacity improvement.

The “variable conditions” settings could be used when conditions were such that the rails were not dry and could also be used at times when a slight relaxation of run times was acceptable (e.g. early morning, between peaks, evening). The compromised adhesion brake performance of the RS would need to be compatible with the ATO brake rate defined for this range of adhesion.

The “degraded conditions” settings would be used when conditions were such that the adhesion was below the range covered by “variable conditions”. The compromised adhesion brake performance of the RS would again need to be compatible with the ATO brake rate defined for this (lower) range of adhesion. Any special measures to avoid ATP tachogenerator wheelset spin or slip would need to be effective under “degraded adhesion” conditions.

In general, the operational preference is to operate the same service for as much of the year as possible, with a reduced performance under adverse conditions (< 5% of the year). This approach requires two performance settings - "normal" and "reduced". The higher the "normal" settings, the more extensive the required mitigation measures to counter compromised and degraded adhesion conditions.

3.9.2.2 Adhesion Limits – Individual Wheelset

The adhesion required for any individual wheelset, to support the acceleration and service braking demands for the train, needs to be compatible with the range of credible adhesion conditions.

In principle, if individual trains were equipped with the ability to determine whether the railhead was dry or not, then tunnel levels of adhesion could be utilised (on the open sections) under dry rail conditions.

The adhesion demand for any individual wheelset, to support the acceleration demands for the train, should not exceed the following values:-

Motoring		
	Existing Mitigation	Enhanced Mitigation
Maximum acceleration – tunnel	0.2	0.2
Maximum acceleration – open – from stationary	0.1	0.14
Maximum re - acceleration – open – (moving train)	0.06	0.1

The adhesion demand for any individual wheelset, to support the service braking demands for the train, should not exceed the following values:-

Service Braking		
	No cross blend	With cross blend
Average ATO brake rate - tunnel	0.12	0.16
Maximum ATO brake rate – in tunnel	0.15	0.2
Maximum ATO brake rate – in open	0.12	0.16 *
Average ATO brake rate – open – steady rain adhesion category	0.09	0.16 *

* If a cross blending system is to be provided, then, in the open sections, its capability should be variable and linked to the demanded brake rate to avoid an inappropriately high adhesion demand when using low brake rates. Additionally the system may be arranged so that cross blending is automatically cancelled if wheelslip/slide occurs on that bogie/vehicle

3.9.2.3 Acceleration Rates

The following maximum acceleration rates (for the train) are for level track conditions

	Existing Mitigation	Enhanced Mitigation
Maximum acceleration – tunnel	1.4 m/s/s	1.4 m/s/s
Maximum acceleration – open – from stationary	0.8 m/s/s	1.2 m/s/s
Maximum re - acceleration – open – (moving train)	0.5 m/s/s	0.8 m/s/s

Unless agreed otherwise, the acceleration to be used when departing an open section station should be less than that used in tunnel sections, to reflect the increased risk of lower adhesion and the consequent increased risk of wheelspin and the potential risk of resulting rail damage.

Unless agreed otherwise, a lower rate of acceleration should be defined for use when re-accelerating between stations. This is to reduce the risk of squat like defect formation in the rails, resulting from wheel spin at speeds between 15 and 30 kph.

The implementation of appropriate and effective mitigation measures (e.g. enhanced wheelspin control, routine railhead grinding) should enable a higher level of motoring performance.

The specific values used should comply with the maximum motoring adhesion demands for individual wheelsets (see above) and should take account of the percentage of wheelsets powered in the assumed train formation.

The acceleration of the train, if 100% wheelsets are powered, is the wheelset adhesion limit multiplied by 'g'. (i.e. for a wheelset adhesion limit of 0.1, the equivalent train acceleration is 1.0 m/s/s).

If the percentage of powered wheelsets on a train is less than 100% then the train's acceleration will need to fall to avoid exceeding the adhesion limit for an individual wheelset.

For example, if only 50% wheelsets are powered then to accelerate a train at 1.0 m/s/s would require an adhesion level of 0.2 for the powered wheelsets. An imposed wheelset adhesion limit of 0.1 would mean that the train's acceleration could not exceed 0.5 m/s/s.

With enhanced mitigation, an acceleration rate of 0.8 m/s/s on a train with only 50% of its wheelsets powered could be considered. This would require an adhesion level of 0.16 but the imposed wheelset adhesion limit of 0.1 would mean that the train's acceleration could not exceed 0.5 m/s/s.

3.9.2.4 Service Brake Rates

The following service brake rates (for the train) are for level track conditions.

Average ATO service brake rate – tunnel stations	1.15 m/s/s
Maximum ATO service brake rate	1.4 m/s/s
“Normal” ATO service brake rate – open stations	0.6 – 0.9 m/s/s *
“Reduced” ATO service brake rate – open stations	0.3 – 0.6 m/s/s *
Maximum service brake rate (manual)	1.15 m/s/s

The service brake rate to be used when braking into an open section station should be less than that used in tunnel sections, to reflect the increased risk of compromised adhesion.

For open section ATO operation, a minimum of two levels for each brake rate should be defined – the “normal” ATO level and a “reduced” ATO level for use under adverse conditions.

Unless agreed otherwise, the “normal” ATO rate of service braking, when braking between stations, should be set lower, for passenger comfort reasons, than that defined for braking into open section stations.

* The “normal” open section ATO brake rate should be within the range 0.6 – 0.9 m/s². An associated “reduced” open section ATO brake rate should be provided. This should be within the range 0.3 – 0.6 m/s². The precise settings will be determined based on the susceptibility of the particular line to degraded adhesion (e.g. leaf contamination) and the braking performance of the rolling stock under degraded adhesion conditions. The precise settings may vary between types of site (e.g. “leaf fall vulnerable” and “not leaf fall vulnerable” sites).

The ability of the rolling stock to achieve the normal ATO brake rate under degraded adhesion conditions will depend primarily on the sanding systems installed on each train and the train's speed at the start of a stop.