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His extensive experience in electrification encompasses the design of complex systems using the proprietary Dynamic Rail System Simulation (D-RSS) tool, as well as infrastructure construction assurance through static wire geometry and dynamic interface assessments. Having supported numerous testing campaigns, Dr. Baimpas is now focused on developing data-driven alternatives to full-scale pantograph testing, championing a "get-it-right-first-time" approach to solve one of the most significant technical and economic challenges in modern rail electrification.

THE ELECTRIFICATION SERIES: INTEGRATION ACROSS ALL AREAS OF THE RAIL INDUSTRY

MIDLAND MAINLINE OLE125 RENEWALS PROJECT: EXTENDING LEGACY OVERHEAD INFRASTRUCTURE LIFE SPAN FOR DECADES

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ABSTRACT:

The OLE125 programme on Midland Main Line (MML) set out to raise the permitted line speed of the legacy Mark 3B overhead line equipment (OLE) to 125mph for new electric rolling stock introduced in July 2025. The project adopted a minimum-viable-product strategy, targeting specifically system elements that govern pantograph–catenary dynamic interface performance. In 2020, SPL Powerlines UK introduced a revised "MK3B-05-AT-S" configuration, with dynamic behaviour assessed using T-RIS D-RSS modelling. Following basic system and allocation design, construction began in September 2023 to adjust system tensions and undertake re-droppering and re-grading where required. Progressive, evidence-led assurance was applied to verify construction tolerances, while pre-existing geometric exceedances and contact-wire wear were addressed opportunistically during the works. The enhanced construction-assurance methodology provided a clear line of sight from modelling to field validation, enabling Entry into Service (EiS) on a span-by-span basis with demonstrated compliance to performance targets within each run. This targeted renewals approach extends the useful life of the legacy OLE, delivers 125mph capability without full system replacement, and establishes a repeatable method for similar upgrades on legacy Overhead Contact System (OCS) assets.

Keywords: overhead line equipment (OLE), pantograph–catenary dynamics, Mark 3B, renewals, assurance, Midland Main Line, 125mph.

BACKGROUND

The OLE 125 Renewals electrification infrastructure programme set out to increase capacity on the Midland Mainline (MML) route. The outputs enable one additional Long Distance High Speed (LDHS) train path per hour between London St Pancras and Kettering in each direction. Enabling two of these trains to run in electric traction between St Pancras and Corby, and capacity for three non-electric freight services between Bedford and Kettering per hour in each direction.

The new Overhead Line Equipment (OLE) infrastructure introduced on the MML North of Bedford has a permissible line speed of a maximum of 125mph. The South of Bedford section outlined in **Figure 1** consists of OLE varying in age, the oldest installed in the 1980s. The configuration of the system typically can support electric rolling stock up to a top speed of 100mph. The wider infrastructure can support diesel trains to run at 125mph along this route on the Fast Lines. The MK3B-00-AT-S system originally installed, was an updated replacement to the Mark 3A system which was used on electrification schemes before the introduction on the St. Pancras – Bedford electrification in the early 1980's. The Department for Transport (DfT) remitted Network Rail to undertake targeted engineering interventions South of Bedford, to enable an increase in the OLE capability up to a maximum of 125mph enabling the introduction of electric traction to replace diesel traction without a journey time penalty.

The electric traction proposed to operate at the increased line speed are:

- Class 810, both 5 and 10 car mode
- Class 360 in 4, 8 and 12 car modes

With the funding and access constraints given, a full conductor renewal programme was deemed not economically viable. Therefore, the project was remitted to undertake tactical enhancements, utilising the existing OLE conductors in the south of Bedford area to achieve the required line speed improvements.

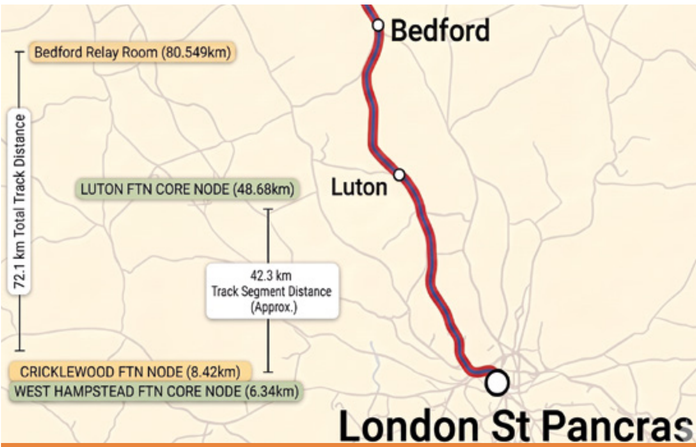

Figure 1: South of Bedford geographical boundary.

THE CHALLENGE

One of the core milestones to achieve a resilient operation of the legacy OLE infrastructure was to improve the OLE to pantograph dynamic interface performance. The MK3B-00-AT-S OLE system basic design principles in addition to the underlying infrastructure condition linked to modifications and maintenance during the asset lifecycle, posed specific performance and reliability risks to the introduction of multi-pantograph formations running up to 125mph.

The team set out to identify the key components within the legacy OLE infrastructure setup and basic design which can be altered to ensure a reliable dynamic interface performance in principle. ‘Enhanced’ 3D Finite Element models of the infrastructure from various locations were deployed on Dynamic - Rail System Simulation (D-RSS) by Train – Rail Infrastructure Solutions (T-RIS) using high resolution static OLE wire profile measurements from the New Measurement Train (NMT). Various design arrangements of the legacy Mk3B system and MML infrastructure were considered:

- Open route performance at higher speeds with multiple pantograph rolling stock including overlaps and geometric defects
- Head-span operation at higher speeds and interference between adjacent track train passing
- Cross-over design using knuckles at support locations and non-tangential wiring along with the specific placement of Section Insulators
- Neutral Section performance using single rod High Speed Arthur Flury components and setup
- Tunnel and Overbridge approach performance with limited encumbrance and associated grading

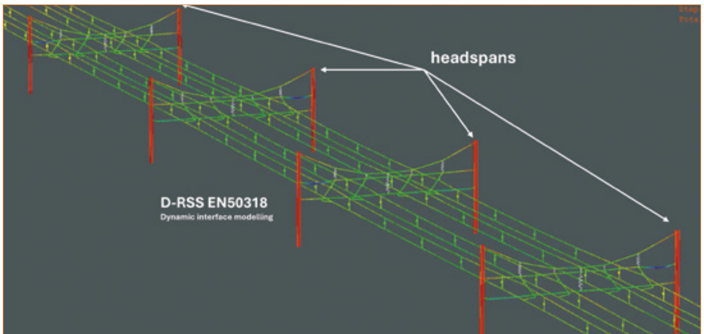

Figure 2: D-RSS models of multiple supported parallel wire runs in an open route configuration at varying degrees of setup tension in the headspan wire.

Figure 2 shows a respective model specific to the multi-track dynamic interface simulation from D-RSS by T-RIS. Supporting the OLE wires with headspans vs. alternative Mechanical Independent Registration (MIR) through portals was considered. It was determined that headspans had insignificant impact to the dynamic interface performance to the pantograph of rolling stock when operating in adjacent lines at opposite directions. Therefore, portalisation of the route wouldn’t have tangible benefits in the increased line-speed.

Further changes in the design layout and basic system parameters were considered arriving at the desired performance levels for the 125mph operation. After all the design principles were decided based on limited trials (worst case scenario pantograph layout) the full list of rolling stock formations of MML were simulated. The results were later correlated with the respective instrumented pantograph testing results to determine the accuracy of the modelling and success of the intervention. An example of the progressive evolution of the OLE system is demonstrated in **Figure 3** for a Class 360 Electric Multiple Unit (EMU). Some of the simulated system permutations were:

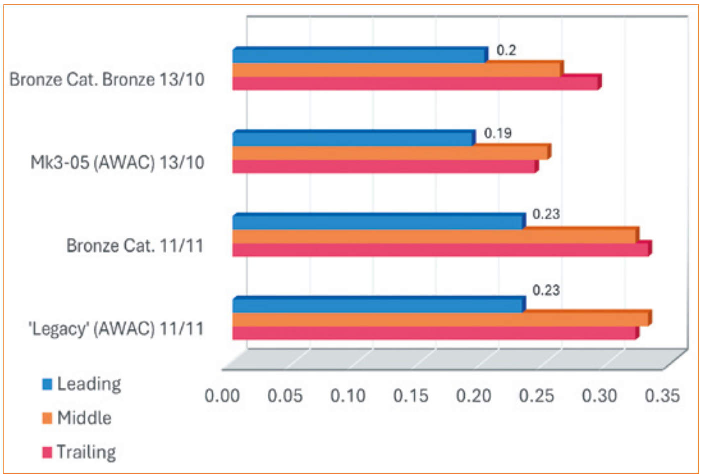

Figure 3: Extract from Remit 2A report (2020) showing the AWAC σ/F_{mean} = 0.23 criterion for the leading BW HSP Mk2 pantograph at 110 mph comparison with the R2A 10/13 σ/F_{mean} = 0.19.

- MK3B-00-AT-S ‘Legacy’ Aluminium-clad Wire Aluminium Conductor (AWAC) catenary benchmark models with existing geometry
- Proposed Bronze catenary replacement at 11/11kN tensions including redroppering and adjusted gradients
- Proposed Mk3B-05-AT-S system maintaining AWAC catenary with revised tensions at 13/10kN, redroppering and adjusted gradients
- Proposed Bronze catenary replacement at 13/10kN tensions including redroppering and adjusted gradients.

The proposed MK3B-05-AT-S system maintaining AWAC catenary predicted a 17% improvement for the worst case performing pantograph rolling stock arrangement which would achieve reliable OLE to pantograph dynamic interface performance levels in the South of Bedford area. This selection further minimised equipment replacement requirements while optimising system performance and not requiring extensive OLE structure renewals.

The resulting MK3B-05-AT-S system upgrades, as part of the OLE 125 Renewals, are summarised below:

- Replacing Balance weight anchor tensioning systems with Siemens anti-fall balance weight anchors
- Re-tensioning of the Catenary and contact wires from 11/11 to 13/10kN
- Re-Dropper whole tension lengths to suit the new system design in line with the new tensions
- Adjust the wire gradients in line with increased speeds
- Headspan renewals where required, replace old with new equipment
- Renew cantilevers to obtain a higher contact wire uplift
- Replace under bridge registration assemblies
- Replacing midpoint anchors in tunnels (Ampthill and Elstree)
- Renew worn contact wire where applicable
- Removing Brown Boveri Section insulators and replacing with BICC High Speed Section Insulators
- Replacing small core Henley insulators
- Removing redundant insulation at redundant insulated overlaps
- Replacing insulation in the switched-insulated overlaps
- Replacing C-jumpers where applicable

CONDITION MONITORING 'BEFORE' AND 'AFTER' WORKS (2023-2025)

Following the full system development, baseline interface performance and static geometry data was captured and analysed using Perpetual-OLE (P-OLE) dashboard to establish benchmark performance for each individual wire-run across the entire route. P-OLE has been developed to jointly analyse the dynamic testing outcome with the analysed static wire profile geometry. The cross-correlation of the two independent samples is key in terms of the validation and future monitoring of the infrastructure condition or movements.

The aspiration was to collect and compare the same data following the works' completion to prove that the anticipated level of performance has been achieved (system assurance) and that the installed geometry is within installation tolerances (construction assurance). The proposed approach alleviated significant cost and timeline from the OLE125 works programme using a data-driven approach to establish the direct project benefits to the infrastructure condition and performance without requiring bespoke test train to run at maximum operating speeds.

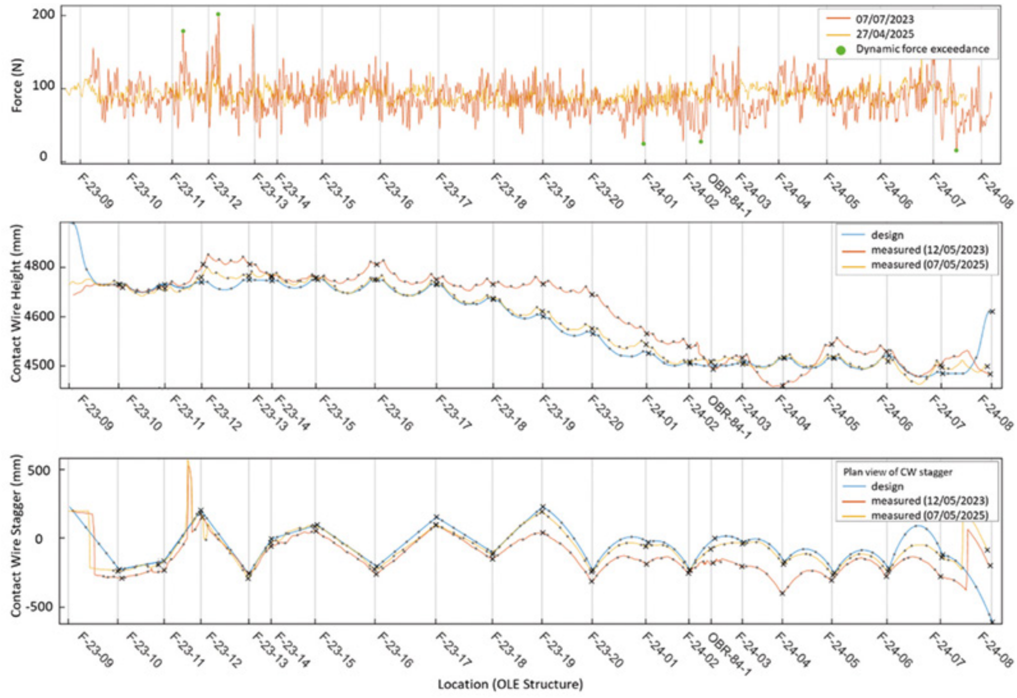

Figure 4: P-OLE data of wire run M36 including dynamic contact force, measured and design contact wire profiles.

Prior to the work, instrumented pantograph data from Mentor and the New Measurement Train (NMT) which form the backbone of the Network Rail (NR) service train fleet were used to collect the pre-existing condition and dynamic interface performance of the South of Bedford area. The Mentor train uses a Brecknell Willis HSA pantograph capable of 100mph and instrumented to EN 50317 [3] requirements. The interface force sample aligns to individual spans to identify statistical performance of each wire run (σ/F_{mean}) and mark up locations of 'discrete' features leading to localised poor performance indicators (F_{min} and F_{max}). The NMT uses a non-contact laser based system to identify existing geometric exceedances using OLE Static Analysis Toolbox (StAT). The static and dynamic interface data were jointly analysed through the P-OLE analytics dashboard previously used in MML Kettering to Wigston and TRU East to provide NTSN ENE [1, 5] construction assurance evidence and root cause analysis.

Lastly, the NMT wire wear data was filtered to identify locations where serviceability limits of the Contact Wire (CW) have been exceeded as well as establishing the CW wear rates of the last 4 years before the OLE 125 renewals project.

NMT (static) wire profile and Mentor (dynamic interface @100mph) were collected and analysed following the works completion. The exercise quantified the geometric exceedance correction following the OLE 125 works marking a drop from 33% affected spans prior to works to < 5% following works mostly in wire runs not covered by the project and with further interventions planned as an outcome of the construction assurance assessment to deliver an asset installed to within construction tolerances. Likewise discrete features (F_{min} and F_{max}) were aligned and attributed to a root cause via the P-OLE analysis informing further 'snagging' activities driven by the criticality of the observed force trace at specific locations [2].

Figure 4 shows a representative P-OLE analysis on Wire Run M36 in the UP FAST direction on ELR SPC1. The data 'prior' show discrete F_{max} force features at the x-over location near structures F23-11 and F23-12. These forces are in the region of 200N and are picked out by a single pantograph formation running at 100mph. Similarly, F_{min} forces are picked up near the bridge approach span at F24-02

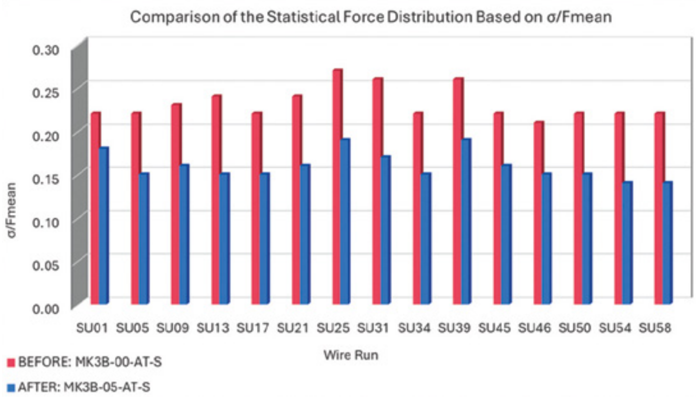

Figure 5: Comparison of the statistical force distribution based on σ and σ/F_{mean}

approximately at 20N. It is evident that the dynamic interface force sample following the works has drastically improved from 'prior' not showing any of those notable forces picked up by the same measuring train. The actual static profile of the wire drastically improved showing full compliance to design.

In addition, the dynamic interface data was used to assess the statistical performance gains of each wire run (σ/F_{mean}) before and after works to establish the performance improvement. A sample of the statistical performance for several wire runs in the UP FAST direction based on the same instrumented pantograph and speed of 100mph is presented in **Figure 5**. A 23% average statistical force distribution improvement was recorded in the UP FAST direction with respective average improvement in the DOWN FAST direction determined at 14%. It is also important to note that performance improvement was achieved across all wire runs adjusted by the OLE 125 renewals project and likewise the analysis clearly demonstrated that out of scope wire runs did not show respective improvement underlining the success of the interventions and the consistency of the Mentor data.

Equally the statistical force distribution improvement is also well in line with the simulation predictions presented in **Figure 3** proving that the system performance milestones have been achieved.

A combined correlation between dynamic interface testing EN 50317 [3] and dynamic interface modelling EN 50318 [4] is provided

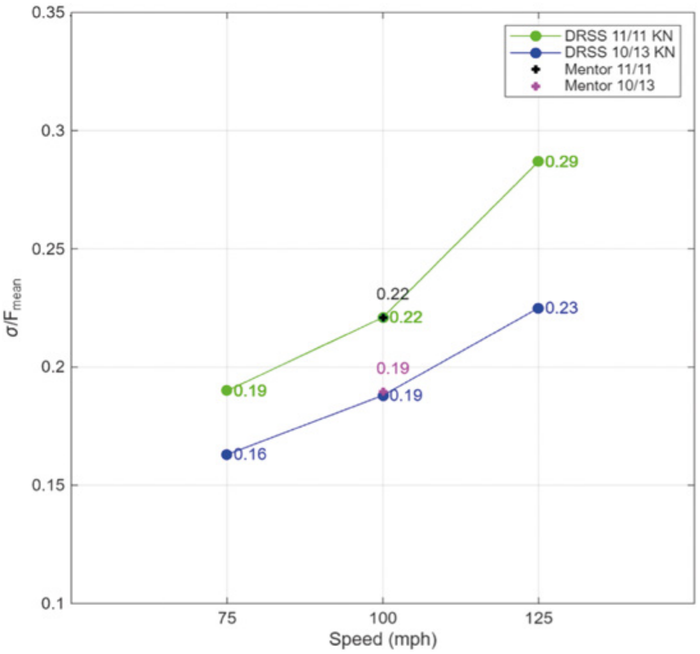

Figure 6: Correlation of Mentor 'before' (11/11) run through wire runs WR68 (SU38) to WR66 (SU44) and 'after' (10/13) OLE 125 works with the equivalent statistical analysis outcome from D-RSS based on a BW HSA pantograph.

Results Summary – Trailing Pan on 3 pan formation at 110mph				
Parameter	Symbol [units]	Measured	D-RSS	Level of correlation (%)
Standard Deviation of Contact Force	σ [N]	31.6	31.1	98%
Maximum Uplift	U_{125} [mm]	31.0	30.6	99%
Range of vertical position	RU_{125} [mm]	42.0	41.6	99%
Mean Contact Force	F_m [N]	99.1	100.1	99%
Maximum Contact Force	F_{max} [N]*	208.7	210.9	100%
Minimum Contact Force	F_{min} [N]*	19.0	15.8	96%
Percentage of loss of contact	NQ [%]	0.0	0.0	100%
*** Exact location and root cause for peak forces captured by the model**			Av. Accuracy	99%

Figure 7: Correlation between D-RSS model and EN 50317 instrumented pantograph testing for the trailing HSP Mk2 pantograph on a 3-pantograph Class 360 EMU formation.

in **Figure 6**. It is noted that the statistical force analysis/correlation has been carried out at the exact location with the addition of actual OLE geometry correlated to within 5mm of horizontal, vertical and longitudinal accuracy respectively for before and after the works were carried out. D-RSS statistical analysis results are shown for 75, 100 and 125mph whereas Mentor results are shown for the 100mph increment available. The correlation between the simulated and measured dynamic interface data is evident proving the correlation and the successful implementation of the Mk3b-05 OLE system.

MULTI PANTOGRAPH FORMATION SYSTEM VALIDATION (2024-2025)

When introducing a new OLE Basic Design the worst case performing rolling stock formations should perform within the specified interface force criteria. That was demonstrated by the simulation carried out at the outset of the project and confirmed using the Mentor testing which was carried out at 100mph and with a single pantograph. To satisfy Notified Body (NoBo) requirements for the multi-pantograph formations' respective performance an additional validation increment was carried out for D-RSS. It is noted that D-RSS had previously been certified by Network Rail Certification Body (NCB) for compliance with the EN 50318 [4] requirements for an AC Simple type of OLE system in 2022.

Suitable data selected for this exercise are summarised below:

- Instrumented pantograph data from the Class 360 UKMS 125 validation testing (KO1 on MMLE, 2021), which includes a 3-pantograph type BW HSP Mk2 configuration (maximum speed: 110 mph)
- Dynamic uplift measurements from UKMS 125 validation testing (KO1 on MMLE, 2021), including measurements on the DF direction at SPC2 101.076 at 110mph
- NMT data collected from Key Output 1 (KO1) (2020–2023)

NCB reviewed the technical validation report by T-RIS and confirmed to be compliant for 3-pantograph formations and up to 125mph. The exercise also certified that the D-RSS outputs obtained an average 98% accuracy when compared to multiple dynamic interface test criteria. This last finding solidified the success of the followed overall system validation approach which did not require multi-pan formation testing. It also paved the way to minimise testing requirements in future projects by following a data driven quantitative approach in addition to an 'enhanced' dynamic simulation outputs.

CONCLUSIONS

An incremental evidence-based approach has been implemented delivering the MK3B-05-AT-S derivative of the previous MK3B-00-AT-S as part of the OLE 125 Renewals project. The system was progressively developed using an MVP approach maintaining large parts of the infrastructure unchanged and aiming the interventions to the key aspects affecting the interface performance. The by-product of re-droppering and height adjustments was the removal of multiple 'discrete' locations in the infrastructure causing poor dynamic interface performance. While the increase in CW tension, overbridge design optimisation and gradient adjustments fulfilled the specified interface force performance criteria for an acceptable resilient performance at 125mph.

Benchmark geometry and interface force data prior to the works were gathered, analysed and correlated with the same data following construction. This exercise guaranteed the geometric setup conformance of the as-built infrastructure as part of an 'enhanced' construction assurance and determined the realised system performance benefit. The improvement in statistical force distribution was in line with the anticipated levels from the earlier modelling exercise. In addition, a Brecknell Willis High Speed – A (HAS) model specific to the used Mentor formation was simulated through D-RSS using the infrastructure before and after geometry leading in identical levels of performance improvement.

Lastly, NCB reviewed an additional multi-pan D-RSS validation exercise based on prior KO1 data from a 3-pantograph formation for an acceptance up to 125mph. The exercise proved that the 'enhanced' modelling approach resulted in 98% average correlation across 9 selected interface force criteria. This result is beyond the EN 50318 [4] levels and proved that such evidence and simulation approaches can be successfully implemented in other projects alleviating significant parts of the project timelines, budget and interface related complexities.

It is accepted that all supplied evidence proved that following the works completion the route will have an acceptable level of dynamic interface performance at 125mph.

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