Proc. of the European Safety and Reliability Conference (ESREL 2026)
Edited by José C. Matos, Paulo B. Lourenço, Michael Beer, Daniel Oliveira, Edoardo Patelli, Hélder S. Sousa, Rui A. Silva and Monica Santamaria

doi: 10.3850/ESREL2026061419_esrel26-p26402-cd

Evaluation of Locomotive Wheelset Maintenance Strategies Using Petri Net Modelling for Wheelset Life-Cycle Management Under Workshop Resource Constraints

Maksym Ocheretniuk

Resilience Engineering Research Group, University of Nottingham, UK, maksym.ocheretniuk@nottingham.ac.uk

Darren Prescott

Resilience Engineering Research Group, University of Nottingham, UK, darren.prescott@nottingham.ac.uk

Rundong Yan

Resilience Engineering Research Group, University of Nottingham, UK, rundong.yan@nottingham.ac.uk

Locomotive fleet management is a key factor in ensuring safe, reliable, and cost-efficient railway operations. Among the essential maintenance tasks in railway transportation is the monitoring and management of wheelset condition, as wheelset degradation directly affects operational safety, ride comfort, and maintenance expenditure. This study presents a Petri net-based modelling framework to represent the wheelset flange and tread degradation process, enabling the evaluation of various maintenance and inspection strategies for locomotive wheelsets. A distinctive feature of this approach is its ability to simulate the degradation process of multiple wheelsets simultaneously. By systematically varying inspection and maintenance policies within the simulation, the model allows assessment of their impact on the key performance indicator, which is wheelset lifespan. Additionally, the model tracks the time that wheelsets operate outside permissible limits, enabling the evaluation of associated safety risks during locomotive operation. The proposed methodology supports dynamic, data-driven decision-making on wheelset maintenance strategy, aiming to extend wheelset lifespan, maximise locomotive utilisation time, and reduce maintenance costs while maintaining high safety and reliability standards. Furthermore, the framework enables the assessment of how different maintenance strategies influence workshop capacity, considering reprofiling machine utilisation, inspection position availability, and workforce constraints. This capability provides valuable insights for locomotive maintenance planning and resource allocation, allowing railway operators to develop suitable locomotive maintenance policies. The study outcomes allow comparison and selection of the most appropriate wheelset maintenance strategy under the given system constraints.

Keywords: Petri Net, modelling, simulation, fleet management, asset management, locomotive, rolling stock, wheelset, maintenance strategies, life-cycle.

1. Introduction

Maintenance strategy selection plays a key role in achieving safe, cost-efficient, and reliable railway operations. Within locomotive systems, wheelsets represent one of the most safety-critical components, with flange and tread dimensions directly affecting performance and operational risk. These dimensions degrade due to rolling contact fatigue (RCF) and are further influenced by maintenance interventions such as corrective and preventive re-profiling. Although re-profiling restores the flange geometry, it inevitably reduces tread thickness, accelerating the approach to operational limits and reducing the overall wheelset service life. Consequently, railway operators seek maintenance approaches that extend wheelset life while limiting costs and improving ride safety.

A number of studies have explored wheelset maintenance optimisation. Ochkasov et al. (2024) investigated a Reliability-Centred Maintenance (RCM) approach for wheelset wear prediction. Zhang et al. (2022) developed a joint maintenance optimisation model based on compound Poisson and Weibull processes, achieving up to a 12% extension in wheelset life and a 27% reduction in maintenance costs compared with conventional strategies. Costa et al. (2020) introduced a data-driven model for wheelset reprofiling and replacement decisions based on survival analysis and Markov modelling. Moreover, Andrade and Stow (2017) evaluated the Economic Tyre Turning (ETT) approach for Great Britain railways using statistical degradation models and Monte Carlo simulation, reporting potential cost savings of up to 4.7%.

In parallel, several studies have focused primarily on maintenance scheduling problems. Wang (2024) introduced a model for maintenance packet assignment and crew scheduling at a train depot. Queueing theory has also been applied to rolling stock depot maintenance scheduling to evaluate long-term system performance metrics for locomotive fleets (Ochkasov et al., 2017; Ochkasov et al., 2018, Ochkasov et al., 2021). Additionally, Louadah et al. (2024) proposed an ontology-based Virtual Depot framework that formalises rolling stock maintenance knowledge and depot resources to support short-term maintenance scheduling. Folco et al., (2024) reviews approach for optimising rolling stock maintenance depot layouts and workflows to improve operational performance. Furthermore, Castillo et al. (2023) proposed a dynamic fleet maintenance management approach that integrates predictive maintenance with joint scheduling based on remaining useful life (RUL) estimates, however, they do not explicitly model detailed component degradation or account for depot resource constraints.

Most reliability-based wheelset maintenance models concentrate on degradation mechanisms and maintenance thresholds, implicitly assuming unconstrained workshop capacity and immediate maintenance execution. Consequently, practical depot limitations, such as restricted availability of inspection and maintenance positions, are typically not considered. Conversely, studies focusing on maintenance scheduling generally neglect component-level degradation and reliability modelling.

This study addresses this gap by integrating wheelset reliability modelling with explicit maintenance resource constraints and extending the framework to the locomotive fleet level.

1.1. *Problem statement*

Wheelset reprofiling is essential for restoring flange geometry and ensuring operational safety; however, it leads to significant and irreversible tread thickness loss, which directly limits wheelset lifespan. While natural wear occurs gradually during operation, preventive reprofiling introduces additional, maintenance-induced tread removal that may dominate total life consumption. In particular, the amount of tread loss during reprofiling depends on the selected target flange thickness, creating a trade-off between safety margins and wheelset utilisation. Conventional maintenance strategies often restore the flange to its original profile, potentially accelerating tread exhaustion. This motivates the evaluation of alternative reprofiling strategies, such as Economic Tyre Turning, that aim to reduce unnecessary tread loss while maintaining high safety standards. Figure 1 shows wheelset profiles before and after reprofiling, illustrating maintenance-induced tread material loss.

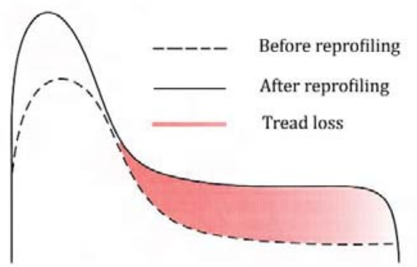

Fig. 1. Wheelset profile before and after reprofiling

To investigate wheelset degradation in combination with depot resource constraints and maintenance scheduling, this study presents an extended Petri Net–based Monte Carlo simulation framework, building on the model developed by Ocheretniuk et al. (2025), which is described in the following sections.

3. Petri Nets Methodology

Petri Nets (PN) are a graphical and mathematical modelling approach commonly used to represent and analyse system behaviour, including degradation processes such as wheelset degradation. Recent research shows that PN methodology is widely applied to stochastic and discrete engineering systems characterised by uncertain behaviour and condition changes occurring at specific points in time. Recent PNs application include railway track systems (Saleh et al., 2023), wind turbines (Wu et al., 2024), hydrogen cells (Ubale et al., 2025) and nuclear power plants (Yan et al., 2023).

The wheelset degradation process was therefore modelled using the PN approach, as it exhibits both stochastic and discrete characteristics. The randomness of degradation events introduces stochastic behaviour, while the evolution between distinct wheelset condition states occurs in a discrete manner over time. PN provides a clear representation of all possible wheelset states throughout the degradation process, as well as the associated inspection and maintenance actions.

A PN is defined as a directed graph consisting of places, represented by circles, and transitions, represented by rectangles, which may be either immediate or timed. Directed arcs connect places and transitions. Tokens located within places represent the current system state, and their distribution, referred to as the marking, defines the overall condition of the system. In general, places represent system states or conditions, transitions represent events or activities, and arcs enable the movement of tokens between places, thereby changing the system state. Figure 2 (a) shows, from left to right, a place with a token, a timed transition, an immediate transition, and an edge (arc).

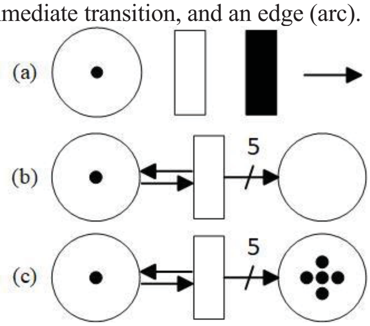

Fig. 2. Petri Nets features

Figures 2 (b) and (c) illustrate the PN firing mechanism. A transition becomes enabled when all its input places contain at least the number of tokens specified by the corresponding arc weights. Once enabled, the transition fires, removing tokens from input places and generating tokens in output places according to the defined arc weights. In some cases, a place may act as both an input and an output, depending on the arc configuration. Transitions might be either immediate or timed (delayed). Immediate transitions fire as soon as their enabling conditions are satisfied, whereas timed transitions fire only after a specified delay has elapsed following enablement. Both transition types may also operate as reset transitions, which reset the marking of selected places to zero when fired. Reset transitions are visually distinguished using green rectangular symbols (Prescott and Andrews, 2013).

To manage situations where multiple transitions are enabled simultaneously, a prioritisation rule is applied. Transitions are assigned priority values, with higher-priority transitions firing first. Alongside the PN framework, Monte Carlo simulation is employed to perform repeated simulation runs using randomly generated input time values. These values are uniformly sampled from predefined ranges derived from normal distribution analysis for selected PN transitions. Monte Carlo simulation is a stochastic modelling technique widely used to evaluate systems subject to uncertainty by repeatedly sampling random variables to estimate probabilistic outcomes (Andrews and Moss, 2002; Bonate 2001).

4. Wheelset degradation modelling

Previously developed model for a single wheelset life-cycle process (Ocheretniuk et al., 2025) was improved and extended with several new features that are discussed below. The core model of a single wheelset degradation, inspection and maintenance process remains the same. This incorporates wheelset flange and tread degradation module shown in Figure 3, inspection and maintenance modules shown in Figure 4 and 5, respectively.

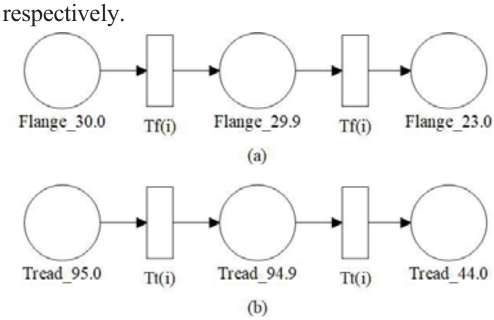

Fig. 3. Wheelset degradation module. (a) – flange degradation states. (b) – tread degradation states

Places from *Flange_30.0* to *Flange_23.0* and from *Tread_95.0* to *Tread_44.0* (Fig. 3) represent flange thickness and tread thickness at a certain point in time, respectively. Each place either flange or tread denotes a discrete state that covers a range of a thickness value, for instance, *Tread_44.0* denotes the thickness range [44.0, 44.1] mm. Transitions *Tf(i)* and *Tt(i)* in its turn represent time of wheelset flange and tread degradation. The first improvement of the model is ability to change flange and tread degradation rate / time wheelset degrades by 0.1 mm after first wheelset maintenance / reprofiling.

Thus, each flange transition *Tf(i)* follows a rule of a normal distribution with $\mu = 5.5$ days and $\sigma = 0.5$ day for initial degradation rate before first wheelset reprofiling occurs. After an event of the first wheelset reprofiling the initial flange degradation rate changes and becomes $\mu = 4.5$ days and $\sigma = 0.5$ day, which means wheelset flange begins to degrade faster after first maintenance interventions. This was discovered during wheelsets measurements data analysis. Additionally, this is conditioned by removing hardened wheelset surface layers when first reprofiling is being performed (Yu et al., 2019). The same situation is with tread degradation where it starts from $\mu = 8.25$ days and $\sigma = 0.75$ day as initial degradation rate and becomes $\mu = 6.75$ days and $\sigma = 0.75$ day after first reprofiling activity. As result, the flange and tread degradation rate / transitions input data automatically changes after first wheelset reprofiling is done.

Figure 4 shows an inspection submodule. Transition *T_a* represents an inspection request event. This transition fires every 30 days requesting an inspection activity for a wheelset. Place *Inspection_counter* collects tokens during simulation to calculate how many inspections were performed. Place *Inspection_is_being_undertaken* holds a token until inspection process is finished, then the enabled transition with the lowest priority *T_b* fires at the end to return a token to place *Pending_inspection* in order to enable transition *T_b* for next iteration. Place Inspection serves as an intermediate place for triggering wheelset inspection. Transition *T_c* distributes tokens to places *Inspection_Flange_n* and *Inspection_Tread_n*, thereby enabling transitions *Tf_in_n* and *Tt_in_n*. Transition *Tf_in_n* is connected to its input place *Inspection_Flange_n* and place *Flange_n* which represents actual state of the wheelset flange. When transition *Tf_in_n* fires place *Revealed_Flange_n* receives a token which implies that we obtained an inspection data of the wheelset flange thickness and inspection process is finished.

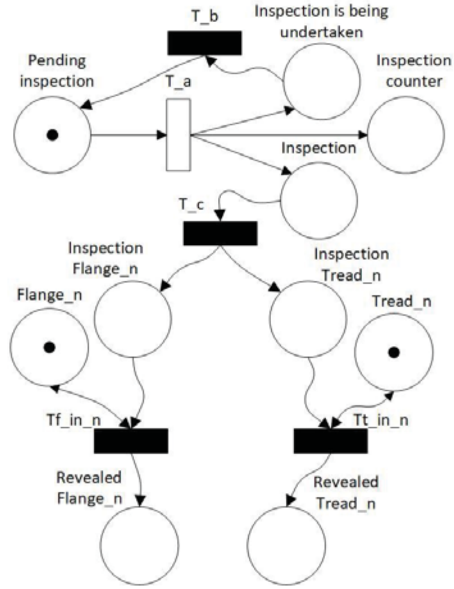

Fig. 4. Wheelset inspection module

When wheelset flange and tread actual conditions were revealed, the model has two options. Both options are based on actual wheelset flange and tread states. The first option is to continue to run wheelset degradation process. The second option is to carry out wheelset maintenance / reprofiling activity. Model will continue to run wheelset degradation if no critical wheelset flange thickness were revealed during inspection. If wheelset flange thickness reaches a critical value of 25 mm or less, then reprofiling activity is required. Figure 5 illustrates wheelset reprofiling module. Transitions *T_fr_25.0* and *T_tr_74.0* represent wheelset reprofiling event. Transition *T_fr_25.0* fires as soon as the critical flange value identified and inspection is finished.

Transition *T_fr_25.0* has four input places. Place *Make_Flange_30.0* represents chosen wheelset reprofiling / maintenance strategy. This means that wheelset flange thickness will be restored up to 30 mm. Places *Flange_25.0* and *Tread_74.0* represent actual states of wheelset flange and tread, respectively.

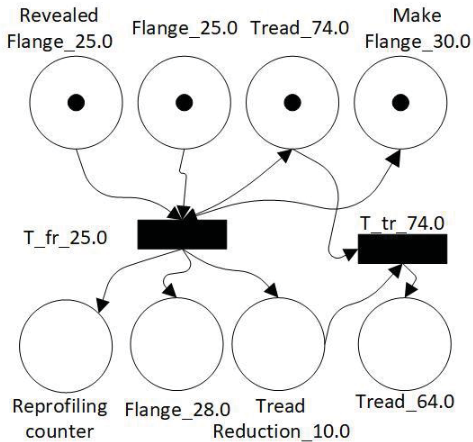

Fig. 5. Wheelset maintenance / reprofiling module

Place *Revealed_Flange_25.0* plays a key role in this submodule triggering reprofiling activity, as it means that critical wheelset flange thickness was identified and wheelset maintenance must be performed. Output place *Reprofiling_counter* is used for tracking numbers of reprofiling. Place *Flange_30.0* is a new actual wheelset flange state after reprofiling as reprofiling strategy was assigned by the place *Make_Flange_30.0*. Each pair of actual flange and tread states has its own tread reduction value. For instance, for the pair *Flange_25.0* and *Tread_74.0* tread reduction value is 10 mm, which is represented by output place *Tread_Reduction_10.0*. Transition *T_tr_74.0* generates a token to output place Tread_64.0 which is a new actual wheelset tread state. Hence, once these two transition *T_fr_25.0* and *T_tr_74.0* fired, this means that wheelset reprofiling is finished and actual flange and tread states were changed from 25 mm and 74 mm to 30 mm and 64 mm, respectively. Wheelset tread material loss amounted 10 mm.

The second improvement to the existing model is the introduction of a dynamic wheelset reprofiling strategy switch during the simulation. Thus, in the old model (Ocheretniuk et al., 2025) two reprofiling types were simulated. The first type was a conventional reprofiling strategy where wheelset is reprofiled only to its initial flange thickness value / full flange profile. For example, when the initial flange thickness is 30 mm, reprofiling can restore the flange only to full flange profile. Consequently, a substantial portion of tread material remains unused once the flange can no longer be restored to its initial thickness, despite the tread thickness still being sufficient for potential wheelset operation.

The second type was Economic Tyre Turning (ETT), under which the wheelset flange is allowed to be restored to a lower thickness when restoration to the initial flange thickness is no longer possible (Andrade and Stow, 2017). For instance, if the initial flange thickness is 30 mm, once full flange profile can no longer be performed, the flange thickness is restored to 29 mm. Operating a wheelset with a reduced flange thickness enables saving of tread material, thereby extending the wheelset life cycle. However, for experimental purposes, a different approach to ETT was used in the previous work (Ocheretniuk et al., 2025). This approach incorporated the following scenarios. Wheelset degradation was simulated starting from a full flange profile of 33 mm, while the target flange thickness was set to 32.5, 32.0, 31.5, 31.0, 30.5, and 30.0 mm across different simulation scenarios.

The new extended model enables the application of the Economic Tyre Turning (ETT) approach through two options. The first option is a dynamic decision-making strategy, in which the wheelset flange is initially reprofiled to the full flange profile subject to a constraint. This constraint involves calculating a new tread thickness value prior to each reprofiling event to ensure that the resulting tread thickness remains within operational limits. If the calculated tread thickness falls below the minimum allowable value of 45 mm, the model selects a lower target flange thickness to allow reprofiling while maintaining the tread thickness within acceptable limits. For example, if reprofiling to the full flange profile of 30 mm is no longer feasible, the model reduces the target flange thickness to 29.5 mm and recalculates the resulting tread thickness. If the recalculated tread thickness exceeds 45 mm, the flange thickness of 29.5 mm is adopted. However, if the tread thickness remains below 45 mm, the model further reduces the flange thickness target to 29.0 mm, and this process continues iteratively until the tread thickness constraint is satisfied with a minimal flange thickness target of 25.5 mm. Figure 6 illustrates ETT dynamic decision-making strategy.

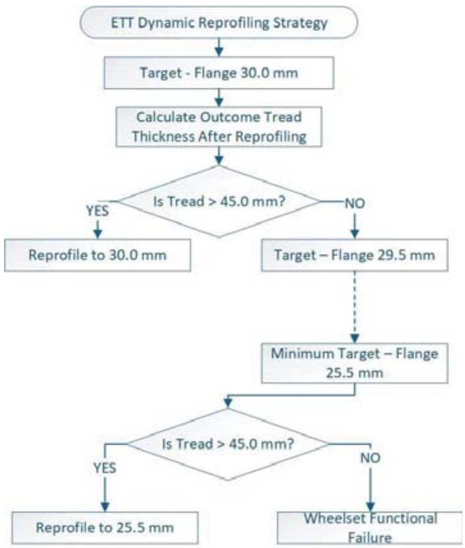

Fig. 6. ETT dynamic decision-making strategy

The second option combines the conventional modelling approach, in which the flange thickness target is fixed below the full profile value, with the dynamic reprofiling strategy change explained above.

As outlined earlier, realistic workshop resource constraints at the fleet level are modelled through the development of a maintenance position availability sub-model and a locomotive-level sub-model. Maintenance position availability sub-model for 2 workshop positions is shown in Figure 7.

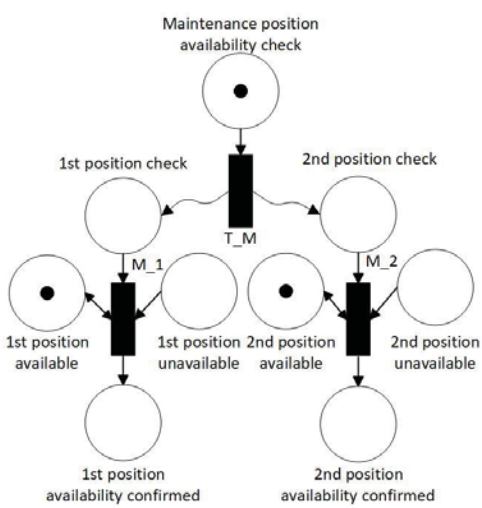

Fig. 7. Maintenance position availability submodule

When an inspection is triggered, the Maintenance position availability check place receives a token. An immediate transition, T_M, then fires and distributes tokens to the 1st position check and 2nd position check places. The immediate transitions M_1 and M_2 subsequently fire, confirming the availability of the first and second maintenance positions by depositing tokens in the 1st position availability confirmed and 2nd position availability confirmed places, respectively. These places are subsequently used to allocate an available maintenance position at the locomotive fleet-level sub-model.

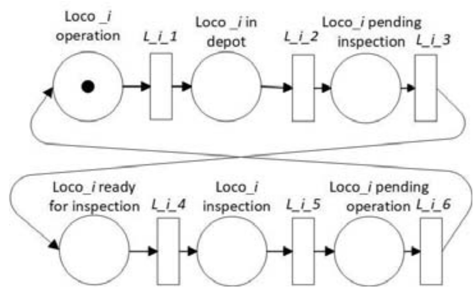

Fig. 8. ETT dynamic decision-making strategy

The locomotive-level places shown in Figure 8 represent the operational states of a locomotive at a given point in time. The transitions illustrated in Figure 8 denote events that trigger changes between these states. For example, transition L_i__1 represents a 30-day interval between consecutive locomotive inspections, during which wheelset degradation occurs. Accordingly, the locomotive is assumed to arrive at the depot for wheelset inspection every 30 days. Transitions L_i_2 to L_i_6 represent additional events, including confirmation of maintenance position availability, the start and completion of inspection and maintenance activities, and locomotive downtime associated with state changes. Each of these events is modelled in detail within separate sub-modules; however, these sub-modules are not presented in this paper due to space limitation.

Therefore, the extended Petri Net model enables the following: simulation of wheelset degradation at the locomotive fleet level; consideration of maintenance position availability; application of different ETT reprofiling strategies through a dynamic decision-making process; calculation of locomotive downtime.

5. Results

The proposed model was used to simulate ten Economic Tyre Turning (ETT) re-profiling strategies incorporating dynamic decision-making. Figure 9 presents the corresponding simulation results. In all simulations, the wheelset initially had a flange thickness of 30.0 mm; however, during the first and subsequent re-profiling events, progressively lower target flange thicknesses were considered: 30.0, 29.5, 29.0, 28.5, 28.0, 27.5, 27.0, 26.5, 26.0, and 25.5 mm. A 30-day inspection interval and the ETT re-profiling strategy were applied consistently across all scenarios. The results indicate that the maximum total wheelset mileage, 497,772 km, is achieved when the target flange thickness is reduced to 26.5 mm. However, this strategy is also associated with one of the highest durations of operation outside allowable limits, amounting to 91,055 km, or 18.29% of the total mileage. From a safety compliance perspective, the 27.5 mm target flange strategy represents a more balanced solution, achieving a total mileage of 478,761 km while limiting operation outside permissible limits to 6.81%. Therefore, the proposed framework enables RAMS-oriented trade-offs between wheelset utilisation and safety risks based on operator priorities.

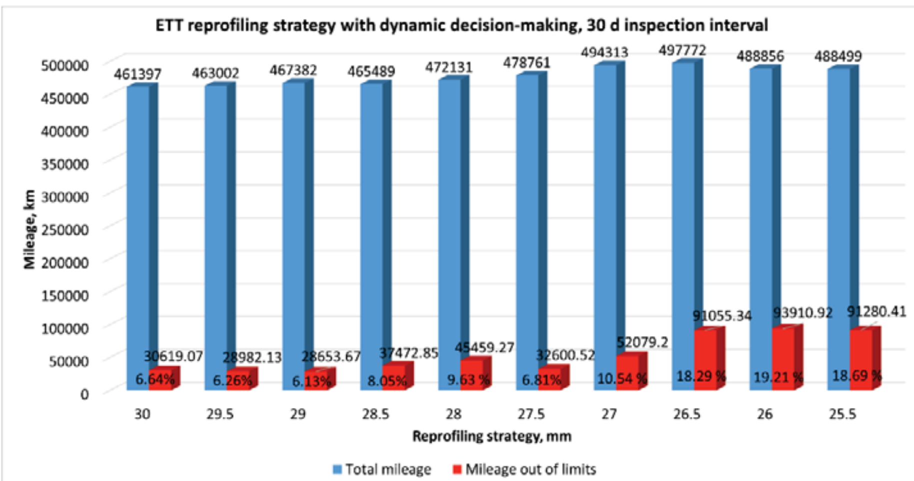

Fig. 9. Wheelset total mileage and mileage outside limits

6. Conclusion

This study demonstrated the applicability of a Petri Net–based modelling framework combined with Monte Carlo simulation for evaluating wheelset maintenance strategies under realistic operational and depot resource constraints. By explicitly modelling wheelset degradation, inspection scheduling, maintenance position availability, and Economic Tyre Turning re-profiling strategies, the proposed approach enables a comprehensive assessment of wheelset lifecycle performance and safety-related outcomes at both locomotive and fleet levels. The results highlight the inherent trade-off between maximising wheelset mileage and limiting operation outside permissible limits, showing that strategies targeting lower flange thicknesses may extend service life but increase safety risk and locomotive downtime. Among the strategies evaluated, a target flange thickness of 27.5 mm provides the most balanced performance, achieving high total mileage while maintaining acceptable levels of out-of-limit operation. The developed model provides a foundation for further expansion toward full fleet-level simulations, where maintenance capacity constraints can be dynamically varied over time to assess long-term fleet performance indicators such as availability, reliability, and utilisation.

Acknowledgement

The authors would like to acknowledge the University of Nottingham for providing the academic environment that supported this research. Special thanks are extended to the Resilience Engineering Research Group for their guidance, expertise, and continued support throughout the development of this work.

References

Andrews, J. D., & Moss, T. R. (2002). Reliability and risk assessment (2nd ed.). Professional Engineering Publishing.

Bonate, P. L. (2001). A brief introduction to Monte Carlo simulation. Clinical Pharmacokinetics, 40(1), 15–22. https://doi.org/10.2165/00003088-200140010-00002

Crespo del Castillo, A., Marcos, J. A., & Parlikad, A. (2023). Dynamic fleet maintenance management model applied to rolling stock. Reliability Engineering & System Safety, 240, 109607. https://doi.org/10.1016/j.ress.2023.109607

de Almeida Costa, M., de Azevedo Peixoto Braga, J. P., & Ramos Andrade, A. (2021). A data-driven maintenance policy for railway wheelset based on survival analysis and Markov decision process. Quality and Reliability Engineering International, 37(1),176–198. https://doi.org/10.1002/qre.2729

Folco, P., Malaguti, E., Sahli, A., Belmokhtar-Berraf, S., & Bouillaut, L. (2024). A flow formulation for the rolling stock maintenance scheduling problem. IFAC-PapersOnLine, 58(19), 516–521. https://doi.org/10.1016/j.ifacol.2024.09.264

Louadah, H., Papadakis, E., McCluskey, T. L., & Tucker, G. (2024). Supporting the Management of Rolling Stock Maintenance with an Ontology-Based Virtual Depot. Applied Sciences, 14(3), 1220. https://doi.org/10.3390/app14031220

Ochkasov, O., Ocheretniuk, M., & Petrenko, V. (2024). Approaches to Improving the Locomotive Maintenance Organization System Through the Introduction of Reliability Centered Maintenance. In Prentkovskis, O., Yatskiv (Jackiva), I., Skačkauskas, P., Karpenko, M., & Stosiak, M. (Eds.), TRANSBALTICA XIV: Transportation Science and Technology. Springer. https://doi.org/10.1007/978-3-031-52652-7_60

Ochkasov, O., Ocheretniuk, M., & Skvireckas, R. (2021). Approaches to the improving the locomotive fleet management system. In Transport Means 2021: Proceedings of the 25th International Scientific Conference, 1054–1058.

Ochkasov, O. B., Grishechkina, T. S., & Ocheretnyuk, M. V. (2017). Approaches to the System Simulation of Maintenance Operations for Locomotives. In V International Scientific and Practical Internet Conference: Actual Problems of Automation and Control (pp. 99–104). Lutsk National Technical University, Lutsk, Ukraine.

Ocheretniuk, M., Prescott, D., & Yan, R. (2025). Evaluating Maintenance Strategies for Locomotive Wheelsets: A Petri Net-Based Modelling Framework. https://doi.org/10.19124/ima.2025.01.21

Очкасов, О. Б., Гришечкина, Т. С., & Очеретнюк, М. В. (2018). Применение методов теории массового обслуживания при моделировании работы цеха ремонта локомотивов. 21st Conference for Lithuanian Junior Researchers "Science – Future of Lithuania. Transport Engineering and Management", Vilnius, 40–44.

Prescott, D., & Andrews, J. (2013). A track ballast maintenance and inspection model for a rail network. Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability, 227, 251–266. https://doi.org/10.1177/1748006X13482848

Ramos Andrade, A., & Stow, J. (2017). Assessing the potential cost savings of introducing the maintenance option of 'Economic Tyre Turning' in Great Britain railway wheelsets. Reliability Engineering & System Safety, 168, 317–325. https://doi.org/10.1016/j.ress.2017.05.033

Rundong Yan, S., Dunnett, S., & Andrews, J. (2023). A Petri net model-based resilience analysis of nuclear power plants under the threat of natural hazards. Reliability Engineering & System Safety, 230, 108979. https://doi.org/10.1016/j.ress.2022.108979

Saleh, A. (2023). An optimized asset management Petri net model for railway sections. Proceedings of Conference, 285–291.

Ubale, S., Remenyte-Prescott, R., Grant, D., Stuart, A., Hague, A., & Saleh, A. (2025). Modelling of Polymer Electrolyte Membrane Electrolyzer Degradation and Reliability. https://doi.org/10.3850/978-981-94-3281-3_ESREL-SRA-E2025-P7304-cd

Wang, J. (2024). Maintenance scheduling at high-speed train depots: An optimization approach. Reliability Engineering & System Safety, 243, 109809. https://doi.org/10.1016/j.ress.2023.109809

Wen Wu, D., Prescott, D., Remenyte-Prescott, R., Saleh, A., & Chiachio Ruano, M. (2024). An asset management modelling framework for wind turbine blades considering monitoring system reliability. Reliability Engineering & System Safety, 252, 110478.

Yu, L., Quan, Y., Liu, P., & Wan, J. (2019). Influence of turning parameters on surface integrity of D840 wheel material. Journal of Physics: Conference Series, 1213(5), 052112. https://doi.org/10.1088/1742-6596/1213/5/052112

Zhang, H., Wei, X., Qinlguan, G., & Zhang, W. (2022). Joint Maintenance Strategy Optimization for Railway Bogie Wheelset. Applied Sciences, 12, 6934. https://doi.org/10.3390/app12146934.