Optimisation of schedules for the inspection of railway tracks

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Review of Railway Track Inspection Schedule Optimisation

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Abstract

Railway track inspection involves a high volume of short-duration tasks (e.g. visual inspection, vehicle-based inspection and measurement, etc.) each of which is repeated at different frequencies and time intervals. It is important to gain as many benefits as possible from the inspection tasks, which incur huge expenses. To date, various optimisation methods have been incorporated into the schedule generation to determine an inspection order for known number and geographical location of tracks. Due to the specific requirements of certain tracks or inspection problem —for example, the number of schedule parameters and one-off or incremental type schedules—researchers have developed more sophisticated and problem-dependent optimisation methods. However, an introduction of new inspection technology and policy for the last five years, especially in the United Kingdom has urged a remodelling of track inspection scheduling problem in order to cope with new operational and business constraints. Thus, this paper conducts a review and gap analysis of previous studies of track inspection scheduling problems from an optimisation point of view. Apart from that, we discuss several potential research interests resulting from the gap analysis undertaken. This study shows that heuristic methods are popular among researchers in searching for an optimal schedule subject to single or multiple optimisation function(s) while satisfying various technical and business constraints.

Keywords

Visual inspection, scheduling optimisation, constrained optimisation problem, railway track, track maintenance management, disruption

Introduction

As stated under the Health and Safety at Work Act (HSWA) of 1974, it becomes a duty of the railway infrastructure manager (RIM) to provide a reliable track system, which in turn ensures the safety of passengers, including staff[1]. Failing to maintain the service performance of tracks at an adequate level can negatively affect an overall railway infrastructure (RI) performance, which is a function of safety, train punctuality, overall capacity utilization and costs[2]. For that purpose, track maintenance and renewal (TMnR) works are generally planned and executed to meet a specific range of safety i.e. what is reasonably practicable[3;4]. Besides complying with safety regulations, e.g. the HSWA, track maintenance offers substantial benefits, such as a reduction in the risk of train derailment[5] and controlling noise and vibration emissions for passenger comfort[6]. Realising TMnR is regular every year and a costly activity, thus the pressure motivates the development of track maintenance model (TMM), see[7], which thereby it can assist RIM organisations in many aspects, such as resource utilisation, possession costs and time periods between two consecutive maintenance interventions[8;9]. In addition, a life extension of life track components can be gained.

Figure 1 depicts a basic decision model of TMnR which consists of two main blocks (referring to the dashed square), track condition analysis and decision-making. To answer the core question in a decision-making block, which is when track maintenance is necessary and when the best time for track renewal is, the block demands an up-to-date, i.e., near to real time, condition status of track and the associated components which can be acquired from the deterioration models[10;11]. Some references, e.g.[12–14], identified condition based maintenance (CBM) as a reliable strategy/approach that can provide a real (or near to real) assessment of a component that instantaneously inform IMs if the monitored component is no longer in normal condition or a fault is impending.

As its name suggests, CBM reaches a maintenance decision based on useful information gathered through condition monitoring. Condition of the targeted component may be monitored on-line (automated, continuous) or off-line (manual, regular, on-site). Currently in the United Kingdom, regular condition monitoring which requires RIMs to perform on-site inspections on the targeted components at determined time intervals, still the primary way of measuring and gathering track geometric characteristics and track structure condition data. Those gathered information is then analysed to facilitate recovery from defects and damages, improvements in ride comfort, and elimination

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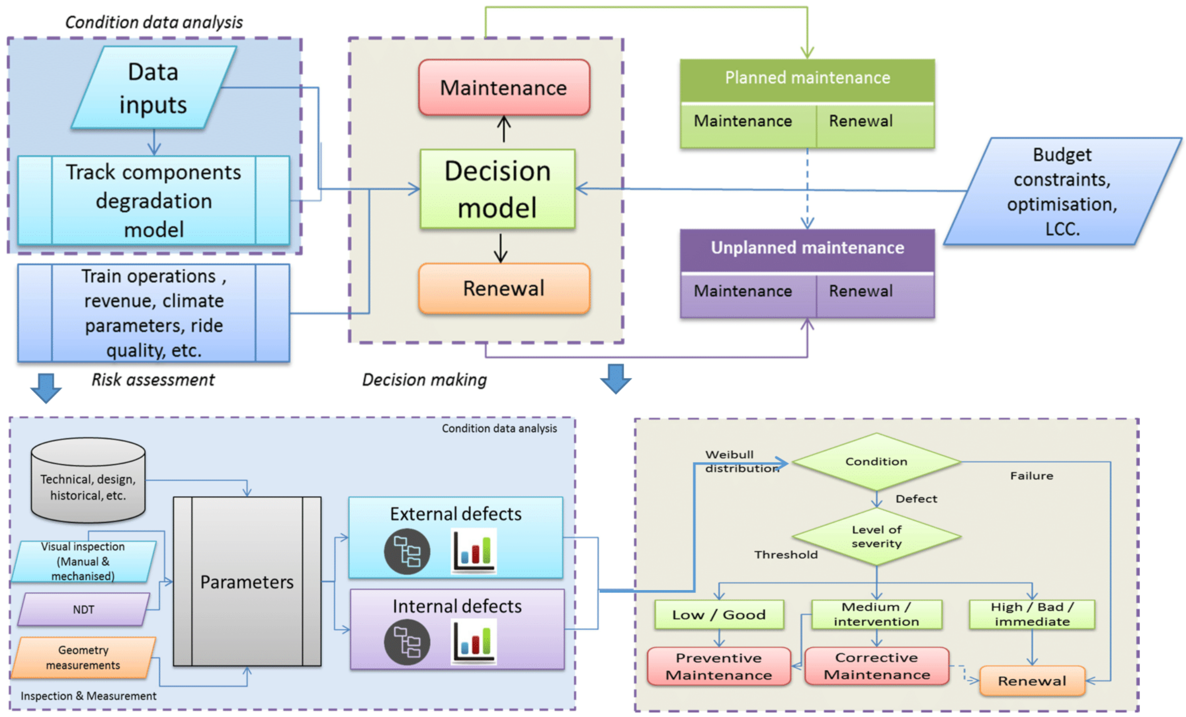

Figure 1. A representation of basic track maintenance decision model, redrawn from Guler[7]

of potential safety hazards[15;16]. Visual track inspection that cover both foot (manned) and mechanised inspection style will dominate the market for many years to come until a self-inspection (automated) regime is ready for full-scale implementation[17]. Note that, on-line condition monitoring may be the best approach for critical, high-valued assets and has short Potential-Functional (P-F) failure intervals. With none of the features, an organisation will suffer a high capital investment for system acquisition, office arrangement and safety, data management and personnel training.

Despite their clear contribution to the track maintenance process, track inspections are fraught with issues, such as causing train delays, the high frequency of line closures, and staff safety. For example, in 2012, the train 2W06 struck the off-track inspector who was standing too close to the inspected track, near to Bulwell station, in Nottingham. In fact, track inspections involve a high volume of short-duration tasks (in the range of one to four hour(s))[18], and it is important to perform them systematically and objectively as inspections incur a possession cost. Longer possession interval result in higher possession cost, particularly on heavily loaded sections where the unavailable slots were likely to have been sold to a freight operator[19;20]. Those issues could, however, be relaxed by incorporating the discipline of scheduling theory when finding the optimized sequence of inspection tasks on a vector of geographically-separated tracks.

Scheduling theory enables users to gain optimal benefits from predetermined activities or tasks subject to a set of constraints[21]. From a RIM perspective, the main goal of scheduling track inspections is to maximize the probability of recording irregularities in track condition data from inspection activities by optimally ordering the tracks to be inspected[22]. To date, researchers have formulated track inspection schedules (TIS) for the last decade of conditions involving both single- and multi-objective function(s), and subject to no constraints or a combination of soft and hard constraints. As different requirements exist from one track inspection problem to another—based on inspection order and railway network size, among other factors—more sophisticated and problem-dependent methods have been developed. This situation, which exhibits the limitations of existing optimisation methods and highlights the significance of problem characteristics in scheduling, appears to be a good inspiration to review literature concerning TIS.

This paper first provides a review of methods, along with algorithms to solve the TIS optimisation problems. Following, this paper discusses opportunities to further study the applicability and suitability of scheduling for on-site track inspections to be equipped with an exit point/policy in the occasions of disruptions. It should be clear that disruption is an event not a process and its presence is unpredictable due to existing of low (poor) probability distribution function. The exit point will allow a planner of TIS to reschedule the remaining prescribed TIS to minimise the impacts of disruptions. One may think stability of the prescribed TIS, adjustments time and costs, and failure risk of rescheduling TIS as some measures to be handled with or without carrying optimisation during an execution of disruption management. Other potential studies to improve effectiveness of an implementation of TIS are part of the discussion session before we make some conclusions about the future of TIS, in particular.

Track inspection schedule problem

Model formulation

A majority of researchers formulate TIS as an optimisation problem. In doing so, the track inspection schedule problem should present at least one objective function to be optimised and a set of constraints, if possible. Although an unconstrained optimisation problem is less complicated to solve, the given solution might become less feasible if some changes occur during execution times. Presenting constraints in the problem formulation restricts the search for solutions only in a feasible region defined by the limitations and challenges that the schedule could face in reality.

The recent studies of a constrained optimisation problem for TIS are presented by[23;26]. Two objectives are captured in their model where the first one is to minimise total inspection times to complete the predetermined number of inspections in the given inspection period. The total time is a summation of total times to inspect all the tracks and travel times among the inspected tracks. In order to benefit as much as possible from the travelling decisions, a quality measure was introduced. The measure is a degree of safety importance of inspections and the study aims to maximize the safety measurement as well. Both objectives are hardly to solve either separately or simultaneously in the presence of nine technical constraints. Among them, a time gap between two consecutive inspections on a same track is imposed. An introduction of this constraint can be viewed as an achievement of past experiment-based studies on railway asset management. For example, Lam and Banjevic[31] proposed an intelligent asset health monitoring system. This system alerts an asset manager with an optimal situation to conduct asset inspection before proper maintenance jobs are assigned. A decision is made based on the level of risk to failure which uses information about the hazard of asset as an input for the system. Kim and Frangopol[30] conducted research with a similar purpose but they used a probabilistic approach to a fatigue-sensitive structure. The statistical-based model generates an inspection schedule that requires a low inspection cost but is able to guarantee inspection quality , at least at an acceptable level. In their proposed model, the cost is calculated based on costs of inspection and expected cost of failure. Benefits of the proposed model are evident not only on the inspection section but they also extend to monitoring scheduling. A similar concept can be found in Kashima[29], that is, a condition-based inspection regime was proposed which in turn means an optimal inspection time interval is determined quantitatively using a structural reliability theory. A series of life cost analyses shows the effectiveness of the proposed method.

Reliability techniques were also applied in large scale railway network systems, as presented in[65]. Generally, the reliability centered maintenance (RCM) techniques offer ground benefits, such as technical insight into planning of preventive maintenance (PM), which allows various levels of adjustments in selected maintenance processes, and clear decision diagrams. In addition, maintenance staff who are consulted for the first time are expected to gain better personal encouragement from the interdisciplinary approach used to make the analysis. From a railway infrastructure case study, the authors demonstrated a wide range of specific benefits, such as reduction in time taken for information extraction, an increase in equipment life that positively affects corrective maintenance costs, and an overall improvement in company productivity. Due to the limited level of risk and uncertainty assessment,[66] revised the generic methodology of the traditional RCM methodology. Under dedicated uncertainty assessments, a matrix score is used to evaluate a series of tasks i.e. identification, categorisation and summarisation, with respect to uncertainty factors. The obtained scores are integrated with thetask and interval assessments, both components being common parts of the RCM framework. The embedded assessment part, enriching the risk and uncertainty assessment in which uncovered uncertainties in the assumptions are made in the standard RCM analyses, are well addressed. On another occasion,[67] proposed a system reliability-based methodology to construct a non-periodic PM schedule for deteriorating complex repairable systems. The methodology makes an estimate of system reliability as the condition variables functions differently depending on the current scenario in the system. In each scenario, an optimal PM schedule is obtained by solving a constrained minimisation problem, which incorporates properties of a specific reliability-based PM model. The proposed methodology offers a basic rule of rescheduling PM, which requires involvement of domain experts experiences. However, no specific guidelines are provided.

Andrade and Teixiera[68] put forward a Bayesian model to assess the evolution of uncertainty in model parameters over a limited life-cycle in rail track geometry degradation. In doing so systematically, a framework to update the initial uncertainties was developed. The uncertainty at the design stage, quantified by fitting a prior probability distribution to the model parameters, is sequentially updated as more inspection data becomes available after operation starts. Following this, posterior probability distributions are used to assess the reduction in uncertainty in geometry degradation parameters. Negotiation of life-cycle maintenance costs could take place upon completion of posterior probability distribution computation. An extended version of the authors work can be found in[69].

Inspection costs are found to be a primary objective in most works of optimisation problem for TIS[26;28]. However, in some cases, an inspection cost is defined as a problem constraint. This occurs in the case of a railway company that has a limited budget for inspections, as presented in Higgins et al.[27]. This work also put forward job sequence, track authorization and travel time as constraints that need to be satisfied when solving the optimisation problem. Two objectives are involved, which are minimisation of disruptions to train services and completion time. The former objective was introduced due to the fact that trains must follow speed restrictions when approaching the inspected area, and to this extent it might cause delays. Too many delays could create a bad perception from the public which is certainly not welcome in a passenger transportation business[24]. Budai et al.[19] extended the work by introducing generalised costs of track possession as an objective to be minimised. This study is unique as it generates an optimal schedule which involves both preventive and routine maintenance works.

An attempt to move away from a periodical practice in managing railway assets can also be observed from the way an optimisation problem is formulated. Ottomanelli et al.[35] developed a fuzzy-logic-based decision making to facilitate rail tracks maintenance which provides a track supervisor more flexibility in terms of deciding which tracks should be accessed and when. With the proposed model, there are no more crisp and rigid decisions and the system will generate a membership value to six maintenance modules, which includes delay of the maintenance as one of them. The fixed periodic inspection always implies a trade-off between inspection cost reduction and timely failure detection. To overcome the above challenges on inflexibility of the fixed periodic inspection, and performance concerns about inspection intervals, non-periodic inspection strategies have been proposed. In[70], the degradation warning threshold was introduced to divide the whole degradation process into normal and warning areas, where a long interval was applied to the normal area, which was then shortened to a predetermined value for the warning area. Overall, the proposed non-fixed periodic inspection strategy is flexible and applicable to precognitive maintenance for the monitoring of system degradation, which can not only improve the inspection efficiency, but also reduce the overall maintenance cost in practice. Theoretically, a non-periodic inspection policy that incorporates recent inspection results and/or environmental condition in the TIS model shows better performance than a periodic policy. However, an implementation of a non-periodic inspection policy for railway track inspection is very challenging due to periodicity of train timetables, prioritisation on track access given to freight companies, and of course, resource constraints.

Konur et al.[23] extended their TIS research by discussing the potential of inspection results as an input to a risk of failure analysis of tracks. Reliability and a crack growth approach have been studied as a case study to effectively export track inspection results to a rail-related failure risk measurement analysis. Their primary concern is to optimally utilize track inspection data in the context of track inspection but is not intended to be a primary source of data. In[71], the risk of failure is controlled by introducing two penalty cost functions for exceeding maintenance thresholds into the total cost of TIS model. With these functions, a different inspection policy i.e. interval could turn out non-optimal due to the function changes. The findings point out that the effect of changes in model inputs on total cost formulation could generate a different inspection strategy. Meanwhile,[72] proposes a risk of accident cost function which is derived from the cost of derailment and the probability of safety fault occurrence that can cause derailment in the interval between maintenance execution and the next inspection. However, use of proposed risk function is limited under certain assumptions namely tracks are identical regardless of geometric characteristics, location (curve or tangent), substructure characteristics and construction time and maintenance history. Further sensitivity analysis is strongly suggested to justify the claim that tracks with higher degradation rates requires more frequent inspections and PM.

It is not an exaggeration to say that both inspection and measurement vehicles are a great creation for track inspection and maintenance. A train-borne with plain line pattern recognition technology, for example, not only increase inspection integrity but also reduces inspection times as compared to a foot patrol[34]. However, it is crucial to assign those vehicles on tracks at low expenditures without comprising the high quality of safety standards. To achieve both objectives, Podofillini et al.[22] developed a risk-informed methodology to determine optimal strategies for how to assign the ultrasonic inspection vehicles. Realising the restrictions that underlie the inspection and maintenance procedure in the real world, the study developed a model to verify the workability of the proposed solutions. In addition, no technical constraints have been presented in the problem formulation, unlikely in Peng et al.[36]. Periodicity constraints, penalty costs imposed due unfinished inspections within the allocated time windows and avoiding task completion by an unauthorized inspection team were taken into account with regards to an optimisation problem for an inspection vehicle. By taking into account the complexity of the abovementioned realistic issues, the single objective problem was formulated as a vehicle routing problem (VRP) . VRP is a popular methodology to serve a known number of orders/clients on the given network with a fleet of vehicles of minimum cost while satisfying side constraints such as time windows[25;33;37]. A solution of the proposed model was found to be superior than one produced through a manual procedure when it was tested for a short-term schedule i.e. a partial complete schedule. Meanwhile, Lannez et al.[32] also proposed a single objective VRP but a solution of the problem has a minimum total deadhead distance while satisfying six constraints, where two of them are the vehicles limitations.

Solution method selection

A schedule may be described as a sequence of tasks or activities that will be sequentially performed for a given time period. The feature gives track supervisor two options; to either prepare a prescribed (master) inspection schedule, or do it partially as an interval-based routine. The former scheduling mode is the practice of producing a complete schedule before the beginning of a business operation period. Under the time-rigid option, tracks under IM supervision will know in advance about time and inspection tasks that will be performed on them. Besides that, a prescribed schedule offers other benefits, such as the schedules objectives being known prior, in real-time status of company resources e.g. man power and equipment is always available and the planning team have to experience the exhaustive schedule design process only once. To attain those benefits, an associated optimisation problem requires approximation methods to search an optimal schedule(s) as the search space size grows exponentially to a number of problem instances[44]. Should be noted that, there is no global panacea in solving optimisation problem and the solution method selection is generally driven by problem characteristics. Complexity of the problem would increase with participation of constraints and objective functions evaluation. To cope with a rough problem environment, a metaheuristic method is applied to track inspection schedule problems.

A metaheuristic method produces a solution(s) close to an optimum condition but is not an exact solution. The method is initiated with a single or a set of candidate solution(s) and improves them iteratively with regard to identified criterion. To utilize the method, no assumption about the problem is required; however, in some situations, algorithm parameters need users inputs. One of the metaheuristic methods that is popularly and widely used to schedule problems in a class of NP-hard is genetic algorithm (GA)[24;41]. Readers are referred to Mitchell[42] and Dorit and Hochba[40] for fundamental readings about GA and NP-hard problem, respectively. Podofillini et al.[22] applied GA to search Pareto efficient inspection/maintenance strategy in their bi-objective optimisation problem. Their strategy to not apply decision makers preferences in prior of GA caused too many solutions that were presented for trade-off analysis. At this stage, decision makers can get a preview of any schedule from the solution lists and also understand a relationship between schedules objectives in the decision making process[39]. A min-max method was introduced upon completion of the search process to downsize the solutions set, where a clear separation could be observed between solutions. An application of GA could also be found in the technical report[23] where the algorithm was used to determine optimal schedules for an ultrasonic inspection vehicle. With application of GA, two objectives of the problem (minimisation of total inspection times and maximisation of inspection quality) were satisfied in the search simultaneously, and the overall results outperformed what they received from greedy heuristic algorithms[26]. The finding indicates that without considering full specificity of the problem a global optimum schedule can be found for the inspection vehicle. However, it had not always occurred where in most situations, especially involving large-scale problems and/or short scheduling horizon, a heuristic method is sufficient to determine an optimal solution for the NP-hard problem[45].

Scheduling of track inspection can be viewed as a combinatorial problem that easily becomes an NP-hard problem when a large number of tracks are involved. Peng et al.[36] customised a traditional heuristic algorithm to handle the complex single-objective routing inspection schedule problem. Algorithm customization was made by incorporating an incremental horizon approach which was able to control the growth of an initial schedule, i.e. short-term or long-term horizon. In particular, two subroutines; task-assignment and task-interchange, were embedded in the approach. The former subroutine is a 7-step algorithm that locally improves a solution obtained from the latter subroutine. The proposed heuristic algorithm over-performs a manual scheduling procedure in short-term horizon but an improvement is expected in future for a long-term horizon schedule.

In a different project by Peng et al.[43], the first author of the work[36] and her different research team proposed an integrated framework of clustering algorithm and iterative heuristic algorithm for solving a large-scale track maintenance schedule problem. Under the solution framework, maintenance activities are initially separated based on the probability level of constraints violation before tentatively being assigned to a number of teams by a clustering algorithm. The similar concept of clustering maintenance tasks in prior also can be found in[19]. Contrarily, the latter article aims to group non-cyclic and cyclic maintenance activities and perform them within one track possession. Four heuristic algorithms were applied to the problem which aimed to determine an optimal schedule of railway preventive maintenance. Mixed results from a series of testing suggest that the selection of algorithm to the problem is very user-dependent.

Meanwhile, a dendrogram (a hierarchical clustering technique) was used to determine groups of descriptive variables related to rail preventive and corrective maintenance[74]. Interestingly, the analysis discovered that greater track length leads to a higher probability of a rail break in track section level. Unlike track, which is a linear asset, estimation of the probability of rail breaks in switch and crossing (S&C) is given by a combination of tonnage and the number of S&C points. In[75], an assessment of the risk of hazardous material transportation by rail is performed in a segment-specific manner. The research empirically shows that an overall route risk can be reduced through delivering frequent inspections on small numbers of high-risk track segments.

With a specific decomposition technique, as presented in[32], an exact optimal schedule can be retrieved from a heuristic method. However, the proposed method was successfully applied to an arc routing-type problem and it is highly probable that it does not directly work in other cases as it is the nature of the heuristic method. Higgins et al.[27] also succeeded in obtaining an exact schedule but their heuristic algorithm is based on Tabu search. Despite the method is simple and powerful to solve combinatorial optimisation problem its execution time and overall quality could be affected by neighborhood evaluation scheme and size of search list, respectively[38].

Potential research

Depending on the type and size of the railway network, track inspection costs would reach millions of dollars and become a time-consuming technical task[18;48]. To perform inspections effectively, scheduling has previously been incorporated where a track supervisor searches for a schedule which optimally achieves several recognized objectives. Past study has shown how conveniently the TIS problem can be solved by modelling it as an optimisation problem. Table 1 summarizes how the selected study dealing with TISs. The number of articles this paper has reviewed actually more than what Table 1 includes but we tabulated pertinent cases that either have unique modelling approach, optimisation criteria, problem constraints or a suggested solution.

Table 1 also shows that most of the studies focused on cost minimisation where a direct (principal) inspection cost was not one of the cost components except in Kim and Frangopol[30]. This situation appears realistic due to the fact there is very little rail companies can do to reduce their direct costs, which is a function of track length and category[54;62]. Each category associates with a specific inspection requirement such as minimum number of inspections per year[55]. Any attempt to reduce costs by decreasing inspection frequency must able to present the same range of checks, of at least the same level of accuracy currently achieved by manual methods[17].

On the other side, minimisation of indirect costs associated with track inspection or maintenance were extensively studied. At present, the cost was defined by the total travel times and maybe in the future, it could include other factors such as the carbon footprint[50] due to the fact that inspection vehicles are fuel-powered machines and make thousands of miles of journeys in a single year

Table 1. Summary of selected track inspection schedule problems

Reference	Model formulation	Components of cost function	Other optimisation criteria	Constraints	Solution method
36;43	Integration of arc routing problem and time-space network model	Travel costs, side constraints penalty costs	na*	Three categories of side constraints: time windows, mutually exclusive precedence	Modified iterative heuristic with a splitting mechanism
19	Binary programming	Possession costs	na	Time and maintenance work order restrictions and all work must appear at once	Modified greedy heuristics
30	Mixed-integer programming	Initial cost, inspection cost, expected maintenance and failure cost	na	Single constraint only, which is an optimal inspection interval that should be at least one year	Non-dominated sorting in genetic algorithm
27	Integer programming	na	Minimise a weighted delay function	Time and inspection work order restrictions, crew assignment and cost budget	Tabu search heuristic
32	Arc routing problem with 0-1 formulation	na	Minimise total deadhead distance	Inspection frequencies and complex operational constraints such as working shift duration, restrictions, vehicle flow, water supply, track outages and a heterogeneous fleet	A cut and column metaheuristic method based on Benders and Dantzig-Wolfe decompositions
23;26	Combinatorial optimisation problem	Inspection time and travel time	Maximise the importance of inspections	Technical constraints, including a minimum inspection frequency and time gap between two consecutive inspections on the same track	Greedy heuristic algorithm, genetic algorithm
22	Risk/cost model	Operation and maintenance expenditures	Maximise safety information	No constraints in model formulation but they were discussed during trade-off analysis	Multi objective genetic algorithm

of inspection[61]. This factor also has an impact on the environment which will impact the indirect cost, since rail transportation is shifting to be a greener transportation mode[51;52;64]. To quantify both factors in the same units, i.e., a generalised cost, one that monetizes time, environmental and societal impacts could be applied to the cost calculation[53].

Track inspection schedules are heavily dependent on the availability of resources such as staff, machines equipment, budget and the track itself. Running schedules in real time exposes them to disrupted situations. To visualise hazards in a TIS let consider a scheduling problem formulation in Konur et al.[23]. The problem was solved under a batch environment in which modelling complexity issue was managed before the search begins. A straightforward approach to reduce model complexity (i.e. decreasing the computational burden) is to avoid elements that are less likely to occur in reality when formulating a problem[46;59]. Those elements could be identified and studied from an influence diagram[58].

An influence diagram is not a flow chart but it is a simple way to understand the relationship among input uncertainties, structure and decision values. Figure 2 shows an influence diagram associated with the given problem where the oval-shaped block represents uncertainties in the model. Crew strikes, extreme weather, machine breakdowns, authorisations to work, track unavailability , etc., may occur during schedule execution. These might have a negative impact on deteriorating schedule objectives. Anticipating disruptions during schedule execution is problematic, but can at least be reduced by incorporating an incremental approach when designing schedules[36]. Realizing that most disruptions are unforeseeable, many studies through rescheduling; a recovery action that takes place at the time the disruption arises during the schedule execution. A good review of rescheduling in railway operative management can be found in Cacchiani et al.[47] and Fang et al.[49].

As presented in the railway asset management financial report of the Network Rail[63] as well as inspection manuals[18], foot inspections are still significant in track

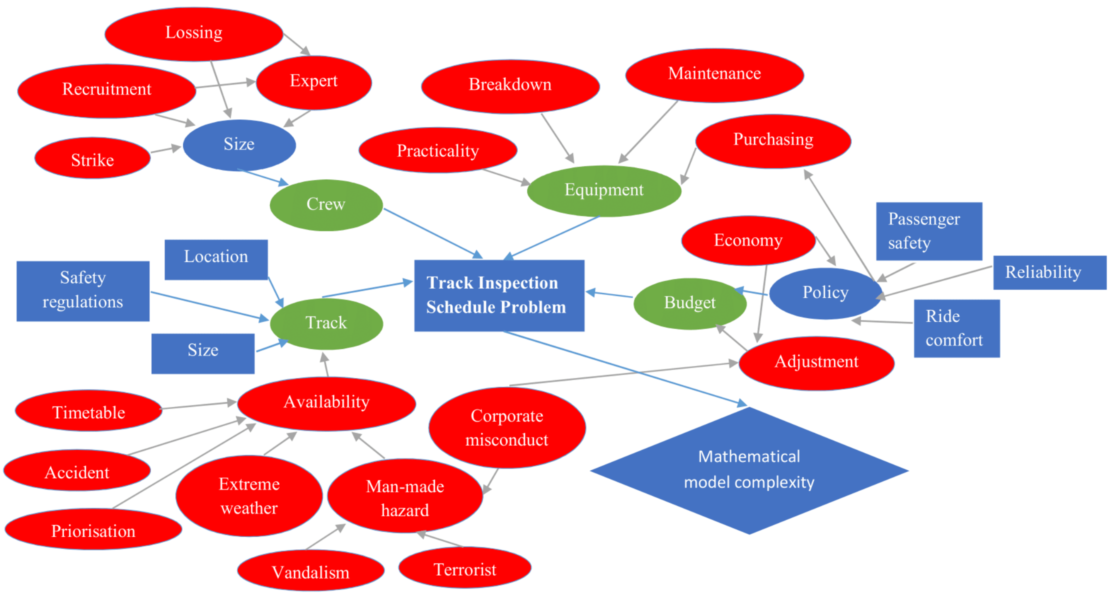

Figure 2. An influence diagram of track inspection schedule problem

inspection programs despite presenting several limitations. However, discussion about integration scheduling of foot and mechanised inspections is rare, as compared to individual type of inspections. Therefore, it is suggested to transfer the current technology of scheduling to mixed-style of inspections. In terms of problem formulation, most aspects can be studied from previous optimisation problems involving inspection vehicles but certainly with some adjustments, especially regarding constraints. For example, the requirement of being physically present on the inspected tracks could be constrained by several factors, such as: working time, weather, track possession, safety regulations, list of tasks, etc. Mixed scheduling of foot and mechanised inspections has potential to be a new research direction. Apart from that, an introduction of on-train measuring systems in railway vehicles[73] offers a wide opportunity for multi-modal track geometry inspection. Nevertheless, the traditional dedicated inspection vehicle is still dominant when it comes to track inspection and maintenance, despite an increasing popularity of on-train technologies. Note that on-board inspection technology is still not mature and comes with engineering faults i.e. the technology is still in the growth phase of the product life cycle. Current safety regulations, track accessibility issues and the large volume of old-fashioned track components restrict this technology from full-scale implementation.

Previous researchers[30;31] worked on finding an optimal track inspection interval which resulted in a publication of inspection policy. The policy proposes an expected number of inspections per year for every track category. For example, 26 inspections per year are recommended for a switch and crossings type B.7 Logically thinking, there will be another 26 inspections the following year, where we think it would be an opportunity to reduce the number. A significant reduction in the direct inspection cost can be unlocked from a small percentage of reductions, particularly when it involves a track category that has a high number of memberships and also requires high inspection frequencies, for instance, switch and crossings. Those savings could be transferred as an initiative to an inspection team to improve their commitment every time they perform an inspection. The concept of Non-Claim Discount, found in vehicle insurance policies, could be a good example and it is worthwhile to study its suitability in track inspections.

In the same vein, an application of Big Data could be incorporated in the post-inspection process that aims to analyse the risk of switching an inspection regime from periodic to non-periodic mode during an execution period. Large volumes of condition data and geometric measurement can become an asset after successfully turning it into available information. As measurement and monitoring technologies have advanced, and become cheaper and more ubiquitous, data-to-information has morphed into a broader discussion about how to manage Big Data[57;60]. However, like many developing opportunities, Big Data also presents a number of challenges. Heterogeneity, inconsistencies and incompleteness, merging data, timelines and privacy of data are the main challenges encountered for performing Big Data analysis[56].

Conclusion

This paper reviews almost all publicly accessed articles about railway track inspection schedules from an optimisation point of view. Due to the limited number of publications available on the selected topic, track maintenance scheduling studies are incorporated together with reviews involving solution methods. We first delivered a background of the scheduling of railway track inspection, focusing on advantages of approaching TIS problems in a structured optimisation framework. This was followed by an in-depth discussion of diversity among TIS problems, particularly in the consideration of objective functions and constraints, that had led to the existence of a heterogeneous collection of optimisation-based schedule models. As a result, we were able to determine the main characteristics of both heuristic and metaheuristic solution methods currently applied in TIS optimisation. In terms of future research in TIS from an optimisation viewpoint, a wide range of opportunities has been discussed according to the knowledge gained from the compiling of results.

The TIS problem has attracted the development of a new heuristic method to solve a single objective optimisation problem. In case of solving multiple objectives simultaneously, the use of a problem-independent algorithm is sufficient. Slow but steady progress was observed in the research topic that urges much more research to be done. This paper suggests that further research could start from studying a new type of track inspection schedule; for example, or explore the possibility of having an integrated foot and mechanised visual inspection schedule. Other than that, an expansion of the current problem formulation, by considering quality measures for schedules, redefining the problem constraints, or introducing a mixed scheduling approach is recommended. Further research also can be initiated in developing a benchmark database about performance of optimisation methods/algorithms in solving track inspection schedules. To date, sophisticated heuristic algorithms are required to generate a near-to-optimal schedule where the use of metaheuristic method actually is sufficient but the given problem has to be approached differently. Apart from that, a potential of multi-objective optimisation in solving the track inspection schedule problem still needs to be identified.

Finally, the track inspection schedule problem can be defined as a function of track, equipment, manpower and time. The complexity of solving constrained optimisation problems can be reduced if interdependent issues among the components can be managed separately without causing a serious degradation in their functionality; either as an individual or a whole schedule. Furthermore, recovery actions such as rescheduling, in the event of a disruption can be implemented directly with the affected components.

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