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ABSTRACT
Over the last few decades, there has been an increasing demand in the need for trains to be capable of running at high levels of efficiency, in terms of punctuality and reduced energy consumption. Such demands have been set in the wake of government initiatives to reduce pollution, which has led to an increased use in trains as a preferred method for public transportation. In efforts to alleviate the strain on rail services, there has been much research in the design and development of advisory systems that perform as a means of maintaining high levels of reliability. Typically, the term “advisory system” is primarily used within the rail industry to describe systems that monitor driving behaviour with the goal of minimizing fuel consumption and to maintain a consistently punctual service, which is known as Driver Advisory Systems (DAS). However, this term is used within this project to describe a system that delivers real time advice to rail operating centres for regulating traffic management in the event of disturbances or when there is potential for a disturbance to occur. The goal behind this objective is to ensure a reasonable degree of failure recovery and/or prevention that would allow rail networks to run dependably and in a resilient manner. This project, therefore, proposes to develop an artificially intelligent advisory system that would operate as a rule based expert system, responsible for making decisions concerning optimal route planning and traffic management strategies for small scale rail networks. There are various techniques in artificial intelligence that are currently used within the transport industry, such as conflict path resolution, probabilistic reasoning and fuzzy logic. Currently, this project is in the initial stages of investigating these techniques and how they may be applied to make safe and effective decisions quickly and how the system may offer advice.

1 INTRODUCTION
This paper presents an initial study, which forms as part of the preliminary stages of a larger research project that aims to develop a formal design framework that precisely outlines a design specification for the development of a future train advisory system. In the context of this project, an advisory system is considered to be a system that provides real-time advice to rail-operating centres for regulating traffic management to ensure that services perform efficiently and that the effect of disturbances are minimised as much as possible. The motivation for developing this type of advisory system is to restore the feasibility of the original timetable in the possible event of a disturbance, given the real-time positions and movements of rolling stock. This is so as to provide a reasonable degree of failure recovery across a small-scale network by minimising the impact of a disturbance.

Currently, the proposed approach to developing a design, which is critically discussed throughout this paper, is to adopt various methods and techniques from artificial intelligence, where it is hoped that the advisory system can be designed to operate as a rule-based expert system. The techniques that this study has considered and discussed within this paper include: representing a rail network as a multi-agent
system; representing expert knowledge on dealing with disturbances and train dispatching; representing logical rules that define the behaviour of infrastructure – particularly signals; and to solve traffic management related problems using state-based searches. However, in applying this approach, many challenges and considerations have needed to be taken into account. One such challenge has been in understanding as to how the problem of reducing widespread delays within a rail network, can be described and represented computationally and with enough mathematical precision that a solution can eventually be determined. Indeed, much of AI research, as noted in [11] has focused on developing such an understanding rather than directly focusing on gaining a solution. However, a further challenge is also in ensuring that a solution can be derived in real-time and that it is able to satisfy hard-lined safety constraints, which immediately adds to the complexity of the problem statement.

This study is motivated towards the application of artificial intelligence since many systems widely used within the transport industry, especially in air traffic control, are developed as rule based expert systems and feature AI techniques such as multi-agent path planning and conflict resolution. In addition, artificial intelligence has been proven as a viable option for rail since many urban transport networks, such as London Underground and Hong Kong Metro [12] are currently using artificially intelligent based systems. What we aim to contribute within this long term research project, is to develop a system that is capable of delivering relevant and “useful” advice in real-time given the current state of the rail network. As noted earlier, this is for the purpose of improving the run-time efficiency of trains such that delays could potentially be avoided or, in the event of disturbance that causes a delay, the network is able to recover by such a margin that the impact of the disturbance is minimised as much as possible.

The structure of this paper is as follows: the following section presents a simple case study of Swindon station, which we use to define an initial problem statement and explain how artificial intelligence is potentially invaluable to developing a solution strategy. This is expanded upon in Section 3, where we present a proposal for developing an abstract system model of the case study example using a multi-agent oriented discrete representation. This section also discusses how behavioural aspects of the rail network, such as signalling rules, can be modelled using various logical expressions that rules that define fundamental system behaviours. The remaining sections address a variety of different scenarios that are typically encountered in the rail network, where we focus on three in particular: (1) path conflicts at junctions (2) assignments to platforms and (3) delay reduction. Each of these problems focus on a particular aspect of the problem statement, as defined in Section 2, where we identify the AI techniques necessary to solve them in real-time and develop an initial outline of a probable solution. Additionally, we briefly discuss how a solution (or collection of workable solutions) could be presented as advice to the end user, who will ultimately be the final decision maker. Section 7 concludes the paper.

2 PROBLEM OVERVIEW AND RELATED WORK
Throughout this paper, we refer to our real world case study example of Swindon station (Figure 1) and the lines that connect Swindon to Chippenham (Figure 2). This example is used to focus on a microscopic perspective of train traffic movements, which is useful for discussion and simulation of behaviours and problems that occur at this level, such as conflict resolution, train dispatching and delay optimisation. Indeed, the scope of our work is currently limited to developing solution strategies that are capable of responding to these types of problems and therefore developing solution strategies on a macroscopic level is not considered. The current objective of our work is motivated towards the development of an intelligent system that determines suitable actions for rail operating centres to perform, as well as justifying the advice it produces. It must also be proven that the advice produced satisfies strict safety requirements and that it is optimised to perform in real time (within 5 seconds). Our problem statement therefore, in the short and long term phases of our work, is how to begin developing an initial design framework for an advisory system that is expected to provide advice that can potentially solve traffic management problems - by minimising the effects of disturbances as much as possible - in real time.
This brief synopsis of what we aim to achieve breaks down into numerous other problem statements, however, in the initial phase, which is described throughout this paper, we first aim to address the following issues: (1) how train scheduling problems can be represented computationally and what the most effective representation is; (2) the types of methods and techniques that are available to solve scheduling problems and the extent in which these are capable of determining a good, optimal or near optimal solution; (3) whether these methods and techniques can be optimised for real time performance (4) how these techniques can be applied or enhanced to design and develop a solution strategy; (5) determining the feasibility of implementing a developed solution strategy and the tools that are required to achieve this; (6) how the advisory is able to perform using the final solution strategy and evaluating its potential usefulness for real world use. Each of these points defines some aspect of the problem statement and will be fully addressed throughout the course of the extended research project. This paper sets a systematic outline for how each of these points can be addressed, which builds a preliminary view of what a potential solution strategy would look like and how this may perform when applied to a real world scenario.

It is possible to simulate real world scenarios by using actual timetabling information of arrivals to Swindon, which has been accessed via Network Rail [12] to determine the movements of passenger and freight trains. In addition, the effects of disturbances enable a degree of realism to be added to the case study. A disturbance in rail networks typically occurs at random and with an irregular frequency. Therefore, we assume that a train can operate in either a disturbance free environment or in an environment where a disturbance, of a variable degree of severity, has occurred. It is expected that a train scheduling solution strategy can promote high levels of efficiency, which in itself can aide in minimizing the impact of the delay caused by a disturbance, although further work on delay optimisation would be required to enable a robust approach, which is discussed further in Section 6. To begin addressing the final point of the problem statement, we state that a key expectation of the advisory system’s performance is to promote a degree of dependability with the rail network, however, such a degree would need to be quantified which we suggest a future research topic.

Our proposed approach in addressing the points of the problem statement is to apply methods and techniques in multi-agent representation, multi-agent path finding and conflict based searches, formal logic and knowledge modelling. Each of these enables an artificially intelligent design specification to be established, which is crucial in eventually developing an advisory system that is expected to operate as a rule-based expert system. These approaches can each be evaluated to determine the feasibility of incorporating it as part of the solution strategy. In recent years, many studies have shown that each technique offers a particularly useful approach in describing and solving certain aspects of a train scheduling problem. For example, Dalapati et al. [2] details the development of a multi-agent oriented representation of a large scale rail system in which trains and stations are both expressed as being associated with an agent that performs interaction tasks relating to train station arrivals and departures.

It is worth mentioning that a multi-agent system is a computerised system that is composed of multiple interacting intelligent agents within a defined environment. An intelligent agent can be described as an autonomous entity that makes observations of its environment and performs actions, with respect to these observations, that are relevant in achieving a known goal [7]. According to the study presented in [2], the rail network is represented discretely to provide a computational interpretation of the rail topology, which agents may operate within as an environment. Stations are considered as being passive agents that simply acknowledge the arrival and departure of a train, whereas trains are active agents in the sense that its goal is to visit each station in its route within a timeframe given by its respective timetable. This study provided a promising testimony to the feasibility of addressing train scheduling problems in terms of a multi-agent oriented representation. However, one limitation was that it exclusively deals with a macroscopic view of a large scale rail network and, as such, very few constraints were required. This enabled the scheduling problem to be greatly simplified. Applying such a technique to a microscopic perspective may prove to be a considerable challenge and difficult to achieve in the long term given that a
Figure 1: Layout diagram of Swindon Station

Figure 2: Diagram of lines connecting Swindon to Chippenham
large number of constrains are likely to be required in order to represent a degree of realism, which adds to the complexity of the problem.

The representation of a rail network as a multi-agent system is further supported by many other examples that focus on rail scheduling problems and delay management strategies. Ying Yu et al. [9] present a system composed of self-interested agents that automatically cooperate with other agents to solve delay handling problems. In this work the idea of Resource Constraint Project Scheduling (RCPS) to achieve a valid scheduling solution was described in which the entire duration of the journey or cost of the system was minimized. Zhibin and Chao have also discussed delay simulation and handling strategies [13] using the basis of a multi-agent system, where agents were described as trains and as a strategy agent (which enforces behavioural rules for trains to solve delay and conflict resolution problems). The idea of using a separate entity to define rules is expanded upon further by Xiao and Greer [3], who proposes an Agent-Rule Class framework for structuring the behavioural properties of agents as logical rules that generate a comprehensive knowledge base for the system. These rules enable a reusable knowledge model to be developed and can actively be used within the implementation to dictate agent behaviours for each scenario it encounters. Although this work does not focus on delay handling or scheduling problems, it does show that use of a separate entity for handling system knowledge can lead to a system framework that is easily maintainable and benefits from advantages such as increased runtime efficiency in execution and reduced processing time. This is demonstrated on a very simple railway example that assumes a multi-agent design.

Several other papers have also adopted the approach of representing and applying system and expert knowledge as a method for solving scheduling and routing problems in railways using a heuristic approach. Knowledge is represented in a computer interpretable format in a process called knowledge modelling [7]. System knowledge can describe behaviours of a system, such as signalling rules and speed limits, whereas expert knowledge literally represents knowledge from experts of a certain domain and is typically applied to solve complex problems relative to that domain. Systems that operate in this manner are regarded as rule based expert systems where expert knowledge is applied as a set of rules that act as a heuristic for guiding a search that derives a solution [1]. One such example was presented by Fay [1], who briefly outlines the development of an expert knowledge base for a decision support system that provides a useful aide to dispatchers in solving train routing and dispatching problems. The system represents knowledge as a series of fuzzy rules and used (fuzzy) Petri Nets to define the overall knowledge base.

A major problem in using an artificially intelligent approach can be found when it is applied to solving the conflict-resolution problem (CRP) in real time, which in itself is a major line of research within the rail industry. According D’Ariano et al. [5], CRP can be defined as “a real time problem to find a conflict-free schedule compatible with the real-time status of the network and such that trains arrive and depart with the smallest possible delay”. An optimal solution to this problem cannot necessarily be derived, although it would be possible to find a good solution that is at least workable using a highly abstract representation that doesn’t take into account the full complexity of a real environment. This is because, nearly all optimising strategies that focus on rail operations, especially path planning, are proven to be NP-complete problems [1, 2, 4, 5, 6]. Therefore, it is unlikely that path planning solutions can have practical applications. This is due to several factors, which is covered but a more through description is provided in Section 4.

Firstly, search based problems that attempt to find an optimal route, using an algorithm such as A*, are P-space hard problems. This means that a solution can be found, but not quickly due to a considerably large search space that must be explored in some detail before a solution can be found. With rail scheduling problems, this persists, but constraints are needed to guide the search and translate into a Constraint Satisfaction Problem. A typical characteristic of this problem, as noted in [7], is that each constraint added, increases its complexity and the time it will take to find a solution. It is possible to transform the problem with a polynomial time complexity, but doing so will result in a severe level of abstraction and
will not represent the original problem realistically. One solution that is available to tackle this issue, is to vastly reduce the search, which will require definitions of heuristics (which must be updated after each run, due to trains moving from one position to another). These heuristics can help in guiding the search to eventually derive a solution. As knowledge represents a useful heuristic, it is sensible to focus on a rule-based approach.

3 SYSTEM MODEL REPRESENTATION

The first stage in developing a design solution for the advisory system is to determine a suitable representation for the problem, which may be applied to model the case study as a practical example of a small-scale rail network on a microscopic perspective. We suggest the development of a framework for designing a system model that is (a) suitable for supporting a multi-agent representation (b) accurate enough to feature relevant constraints for each area of the network and (3) simple enough to ensure that a “good” solution may be found quickly and in real time, which is currently difficult to achieve as noted by [1]. The purpose of defining a good system model is to establish a representation for both structural and behavioural aspects of the rail network and to use this as a preliminary knowledge base as well as a foundation for defining process models. Note that the structure for the final model we propose for the advisory system is of the structure-behaviour-process form (illustrated in Figure 3), which is typically used to model most business operations [3]. According to Xiao and Greer, who use this approach to define an agent-rule class framework [3], the structural model represents key infrastructure and resources within a defined environment. The behavioural model usually represents the rules in which agents are expected to operate by and the process model defines high level processes and additional rules that are applied to complete large and complex tasks – in this case, dealing with disturbances. At each layer, these models define essential knowledge describing specific aspects of a complex environment, problems that occur within the environment as a whole and descriptions of how these may solved systematically. The remainder of this section provides details of how structural and behavioural models may be developed and integrated to form a stable platform that may be used to inject problem scenarios. Sections 4 and 5 discuss how processes may be modelled to respond to these problems and develop a solution strategy.

![Figure 3: Proposed structure of system model applying structure-behaviour-process form](image)

Initially, it is possible to develop a structural model discretely since this would refer to the topology of the rail network and hence define the environment that agents would operate within. This approach is explored in further detail by Dalapati et al. [2], in which a discrete model representing a rail network, RN, is described as being a pair of a graph, G, and an agency, A, that is composed of a number of station and train agents. Our model would propose to use trains, signals and platforms as agents. The formal definition is such that $RN = <G, A>$. According to the study, the graph is constructed of vertices, which represent key infrastructure points (namely stations) and edges that represent tracks between vertices. This type of representation is also applied by Mazzarello and Ottaviani [9], who expand on this further by associating each edge with capacity and speed limit constraints. Based on these ideas, we can simply define vertices as key infrastructure points, such as signals, junctions and platform start and end points, which can be used to define paths as block sections, intersection lines and platform lines. It may be possible to associate nodes and paths with constraints, which would need to be designed. Defining a path
as a block section would be important, since this divides the track line in a way that allows constraints to be added that easily outline the maximum capacity, which would be one train per block, and would prevent other trains from entering a point that has reached maximum capacity.

Another suggestion that builds on these ideas, is to represent a train as an agent that is associated with a route, defined as block sections. The train’s task would be to iterate through each block until it reaches its end destination. A train would also be associated with speed and permission based constraints. In our initial design proposal, speed would represent the state of the train in terms of acceleration, deceleration, cruising and when it is at a full stop. We also associate the time and distance involved for a train to reach a cruising speed from a full stop and also when a train reaches to full stop from a cruising speed. This is considered to an important level of detail since it is an attempt to accurately depict a train’s behaviour, and thereby enabling the advisory system to deliver accurate advice. The interaction between a train and signal agent would be in terms of whether a train has permission to continue forward or not, causing the train to slow down and/or eventually stop.

In terms of developing a behaviour model, our work would be primarily concerned in representing signalling rules and basic traffic management rules that trains are expected to abide by. Firstly, since a train is associated with a route, which is essentially a sequence of tasks of reaching from one block to the next that are needed to complete the job of reaching the station. Blocks are usually described as path between two signals. When a train does enter a block, we can capture its entrance time and then its exit time. This is because a block is assumed to have train detection circuit modules that acknowledge that a train is occupying the path and until the exit time is captured, the signal must display red. Once the train has left and the block is free, the signal may then display green. It is further assumed that conflicts are theoretically avoidable since each train is allocated a specified time slot in which it may access a block. Figure 4, presents a very simple algorithm that illustrates this behaviour:

```plaintext
IF signal is red THEN Train must wait
ELSE IF actual entrance time >= expected entrance time THEN
   IF actual entrance time > expected entrance time THEN
      IF other trains are expected in T time THEN
         Train must wait
      ELSE Train can enter
   ELSE Train can enter
ELSE Train must wait
```

*Figure 4: Simple signalling behaviour algorithm*

Although signalling rules are more sophisticated than this example, this simply demonstrates how we eventually intend to capture system behaviour in terms of representing signalling and traffic rules as a means of representing knowledge of the system. This is a crucial aspect of the model as it provides an essential knowledge base of the rail system as a whole, which, as previously mentioned, establishes the foundation required to define processes.

4 **HANDLING CONFLICTS AT JUNCTIONS**

As trains travel along their respective routes, it is inevitable that at some point in time at least two trains will encounter a conflict scenario. Within our case study, we initially assume that a conflict can only occur at a junction. This is because there are constraints that prohibit trains from accessing a block while it is currently occupied by another train. The same is also true for platforms and in both cases, it is not expected that a conflict will occur due to these constraints. Although the reality is considerably more complex, we aim to deal with additional levels of complexity once a simple, abstract framework is established. Our plans for further work are to develop the advisory system to be capable of handling the type of complexity that is typically encountered in real situations and in understanding how a good
solution may be derived. This section discusses a typical conflict scenario at junctions and how the initial framework of the advisory system can be designed to handle this. We propose that a Conflict-Based Search (CBS) algorithm provides the basis necessary for a potential solution strategy to be designed. However, our future work in this area should focus on examining the performance of a CBS algorithm and investigate ways in which heuristics may be defined to reduce the overall search space and achieve some sort of optimality, which, as we shall describe, is a very difficult problem.

A conflict occurs when at least two trains attempt to access the same shared resource (i.e. a junction) within the same time period [9]. The problem that has captured the attention of many researchers is the ability to resolve a conflict scenario so that the effect of disruption is minimised as much as possible, since it is very well known within the rail industry, according to Rodriguez [2], that a small disruption can easily translate into a much larger one when junctions are involved. An obvious solution would be to introduce more track resources, although this is unlikely since large volumes of land space and investments are needed. Therefore, it is essential to find new methods and models that optimise the use of scarce resources by enhancing scheduling and routing techniques [2]. In our case study example, which features numerous junctions, we aim to develop a process model that achieves such optimality that may be based on the CBS algorithm.

The CBS algorithm associates an agent with a set of constraints, where a path is found from one point to another, such that all constraints are satisfied. A path is generally described in terms of a set of vertices that an agent must visit within a given period of time. A time step is the time involved to make an iteration from one point to another along its path. An agent is prohibited from occupying a vertex if it is already occupied by the time it will reach it, if it is attempting to occupy that vertex under this condition, then a conflict has occurred. The algorithm must therefore be applied to find a consistent path for each agent, where at no point in time does a conflict occur, which describes a consistent solution. According to Sharon et al. [8] the key idea of CBS is to grow a set of constraints for each of the agents and find paths that are consistent with these constraints. If any path has a conflict, then it is invalid, and that the conflict must be resolved before the path can be considered valid.

We propose that this approach may be used with heuristics defined within the behaviour model, which will represent a preliminary knowledge base for the system. The purpose of these heuristics is to attempt to reduce the search space of the algorithm, which is crucial for handling NP-completeness. This is an unavoidable topic when attempting to optimise operational level problems in rail since the very concept of path optimisation has been proven to be an NP-complete problem [8]. This doesn’t necessarily mean that a solution cannot be found, but it will be very difficult to find one within a sensible time frame, or it may be that a solution doesn’t exist. Consequently, optimal and real-time solutions are very difficult to achieve, however, a good solution may be found. Now, while heuristics can be useful in minimising the search space, these alone do not yield satisfactory results, since the knowledge base is always limited and not all situations can be considered in advance by appropriate rules.

The general direction of our strategy in handling conflicts at junctions, would be to first determine if a conflict is going to occur based on a simple prediction of which point a train will be at which point in time, according to its current state. If a conflict is likely to occur, CBS may then be applied to determine how the trains affected may be re-routed or even delayed slightly, so that their paths do not collide. What CBS will potentially be useful in deciding is which delayed train would need to be delayed. In a very simple case, a freight train will always have priority over a passenger train, since it is considerably expensive to stop freight in comparison to passenger trains. Also, a high speed train would have priority over a slow speed train, since it is easier to stop slow train compared to fast ones, however, this may contribute to massive delay on the part of the slow train, which would need to be avoided. But when the trains are equal, determining which one to delay would pose a challenge as delaying train may lead to a delay later on, whereas if the other train was let through, that delay may not occur. CBS would be very useful in solving this problems and for “predicting” if further conflicts may occur through simulation. If conflict do occur
as result on one decision but do not occur from another, then the decision that is unlikely to cause conflicts would be recommended. If both decisions potentially lead to conflicts, then at what time would these conflicts occur and which conflict would have the most severe impact. This is where application of risk analysis may serve as a useful basis for adding more detail to the search and further reducing the search space so that optimal performance may be a possibility. Essentially, a conflict based would be used to determine if, at any point in time, a conflict would occur and if so, what the outcome should be so that the overall cost in time is minimised as much as possible. Also, we would need to consider if there was a possibility of a conflict occurring later on as a result of the decision that was made to resolve the original conflict. If so, CBS would also be used in determining the path and time steps necessary to avoid as many potential conflicts as possible and so that each rain is still able to reach its destination in the shortest possible time.

5 PLATFORM QUEUING AND ALLOCATION
The problem of allocating a platform to a train arriving at a station is, at first glance, quite a simple one to solve since it is a matter of allowing a train to stop and wait at the next available platform, where the direction of the platform line is relative to that train’s point of entry and exit. Platform access can be described as operating on a “first come first served” basis, where many problems concerning allocation of shared resources are handled by rail operators in this manner [5]. Hence it is possible to model platform allocation using queueing constructs. A major difficulty in applying this approach, however, is that it not possible to handle and optimise delays for late arrivals, which can seriously amplify the delay if no platforms are available. We therefore outline an initial proposal for building upon the functionality of the advisory system in terms of defining a delay handling process in the context of platform allocation and train dispatching. This would be established as additional layer of an assumed system model, which was discussed in Section 3. A detailed study that is able to capture dispatching rules accurately and successfully implement these as a heuristic for a search-space algorithm, can serve as a useful platform for introducing additional functions that deal with delays that cover larger geographical areas, which we briefly propose in Section 6.

At this stage of the extended research project, we expect to have developed a system model that represents structural and behavioural aspects of the rail network, which describe essential system knowledge. This is respectively in terms of topology and signalling and traffic regulation rules. We assume that a degree of safety verification is enforced by proving that a derived decision satisfies the constraints defined by rail traffic rules. As described in Section 4, the system model would have been applied to define a conflict resolution problem caused by a disturbance in which a process model can be developed for the purpose of generating a feasible solution. However, only system knowledge would be used to define the heuristics, which would be based on signalling rules, for the solution strategy. Now, we refer to expert knowledge to develop a process model for allocating platforms and dispatching trains to minimise a delay as much as possible. This is because actions issued by a train dispatcher can have large impacts on the traffic behaviour and service quality [1] and that expert knowledge is paramount in handling scheduling problems in this manner.

Based on our approaches, we suggest that an additional process model would define a station in terms of a sub-network of a larger, more complex rail network since this would differentiate between local and global areas. As a train travels from one station to another and is delayed enroute, we describe the scope of the delay as being local and relevant only to the station that the train is approaching. We justify this on the premise that if a train is delayed, the delay is effectively global knowledge, given that it is a requirement for drivers to notify rail operators of lateness [6]. As the train’s path is defined in terms of time steps, each new time step would by incremented by a factor defined by the extent of the delay, which would generate new expected times of arrival for the affected train. Once it finally visits the station, the arrival times for every other station thereafter would no longer be valid and the timetable would need to be adjusted (or re-computed) to counter this. We believe this approach would counteract the delay since
the new times of arrival would be proven to be conflict free and that the train can be dispatched from the station with a new deadline.

Our hypothesis is therefore, that given the topology of a complex station (i.e. 3 or more platforms), it is possible to handle platform allocation problems using queueing constructs where there are no delays. Conversely, when delays do exist, formal dispatching rules applied to an optimized scheduling algorithm can reduce the delay by a limited margin upon arrival. Once the delayed train is dispatched, the system can recover from the delay through the application of a conflict-based path finding search that reschedules the arrival times for every other station of the train’s route, where the revised time does not conflict with any other train arrival times.

Our plans for designing and implementing this aspect of the advisory system would be to either present expert knowledge relative to platform allocation and dispatching as an agent-rule class that describes a process or can extend a pre-existing agent-rule class. However, what is certain is that the process of development – as with any expert system [1] – is to (1) acquire the knowledge necessary for solving the problem (2) model this knowledge in an appropriate manner and (3) develop a structure of the rule base for evaluation. We can then propose an algorithm design that would apply this knowledge to define an overall solution strategy.

To achieve the first point, various sessions must be scheduled for understanding the knowledge which can be in the form of domain area studies, interviews with rail dispatching experts and close collaboration with them in ensuring that the knowledge gained is correct. In terms of the second point, various papers [1, 3, 10] have suggested representing knowledge as a series of fuzzy rules, since the fulfilment criteria for executing certain actions use vague terms. Further investigations on our own part would reveal if such an approach is suitable or whether some other logical representations may be applied, such as propositional logic, probability calculus, predicate logic or a combination of these. The final point can be achieved by choosing a suitable implementation method for the knowledge base, which would depend on how the design framework is finally established. For testing and evaluating the final end product, Fay [REF] presents a criterion that should be addressed, which is as follows: (1) is it possible to acquire the knowledge necessary in a reasonable time period? (2) Is it possible to model the knowledge appropriately? (3) Is it possible to use a simulation environment that is fast enough to produce results? (4) Does the rule based system provide an optimal or near optimal solution? When documenting our final design, we aim to address each of these points, although, we intend to complete this section of work within a period of approximately 5 months.

6 DELAY OPTIMISATION
Following the discussion from the previous section, we propose an extension to the study of delay optimisation methods and techniques, where the final solution strategy may be developed to encompass a wider geographical area. The purpose for this is to potentially enhance the functionality of the advisory system, where it would be able to provide advice for a train covering a much larger distance (i.e. 3 or more stations) by using a collection of local areas describing each station and the lines connecting them. A train’s route, from a local perspective, would be described as transferring from Station A to Station B and then from Station B to Station C and so on, where the previous section described possible delay optimisation methods for this, through dispatching, that would allow a delay to minimised. The approach described in this section aims to look at the overall delay reduction strategy when completing the entire route, from Station A through to Station E, so as to monitor and analyse its performance within a larger local area covering a region. This is essentially for developing an analytical approach for maintaining reliability and dependability within a small regional network and for suggesting methods of improvement, which could be achieved by applying techniques from scheduling theory with AI analytics.

Analytical approaches in AI are typically used in the transport industry for improving reliability and to suggest routes that provide a lower cost. We propose that each step that a train makes through its route, is a cost in time and that the objective is to cover the entire distance of the route in the shortest possible
time. This could be translated into the Travelling Salesperson Problem or Dykstra’s Algorithm, but such approaches may be limited since most routes will be fixed and that a lot will depend more on the driving style, rather than the route. The Driver Advisory System (DAS) already handles this, but it monitors the performance of a single train, whereas our interest lies in the performance of each train within a regional network.

One proposed solution is to associate a train with a state, which would describe various actions completed by a train, and that state would be associated with a time cost. If a train is on time, then a state that contributed to this can be considered as the ideal or recommended state for a train. If, however, a train is late, we can also associate a state with lateness and thereby label this as an un-recommended state. The extent of lateness would add to the degree of the severity of un-recommended state and that the advisory system would need to provide advice for avoiding states which are, for example, highly un-recommended. This advice, which would be provided to an operator, may also be used to support the DAS, although this is merely for consideration and that our plans in this aspect are likely to change. For now, the advice generated would be for the purposes of using analytics to solve scheduling problems.

Now, the advisory system could then be optimised further to predict the likeliness of an un-recommended state occurring, based on the current state of the rail network and possibly by taking in a further input of seasonal changes. This would be in line with research that has taken place so far in determining the possibility of a disturbance occurring. Since precise probabilities of a disturbance occurring is generally unknown, since these are random events, we can use data analytics to determine the frequency of an un-recommended state (of varying degree of severity) that has already taken place over a period of time. The most frequent would be associated as being probably the most likely reason, where the behaviour of advisory system would be suggest actions that may prevent such events of occurring since it can be considered of having a high degree of believability that the event will, at some point in time, occur. In contrast the least frequent event is the one that is considered to be least likely to occur, where the advisory system would place little emphasis in preventing it, since it may or may not occur. The precise possibility of the probability of an event occurring is uncertain, where techniques from probability theory may need to be applied, from the results of the analytical approach, to enable reasoning under uncertainty.

At this stage, this part of the work is very hypothetical and highly ambitious and is therefore considered to be an extension of the extended research project. It is also one of the more complex aspects since it deals with sophisticated reasoning techniques based on very broad and complex theories. If we were to tackle this, we would primarily focus on the reliability aspect using AI analytics for the purpose of analysing the performance of a regional network and identifying areas that may need to be improved to enhance reliability, and thereby optimise and/or prevent delays. This alone would be sufficient for the advisory system to provide some useful offline advice to rail operating centres, who would then prompt the driver further and bolster the performance of the DAS. If successful, we would then start to define precisely what the state of a train is and then monitor whether that train was on time, based on the state it was in. This is would, in some way, provide an element of machine learning since the system would learn the types of states that lead to punctual performances and those that don’t. The system would trace through each action performed within the state and identify the cause for lateness, where advice would be given to determine how best to avoid such occurrences. Would then apply advanced reasoning techniques to determine the likeliness of such an event occurring.

7 CONCLUSIONS
This paper has presented the work that is currently proposed for the purpose of developing a solution strategy that would serve as an essential design framework for a future train advisory system. From what has been discussed, our plans for future work include developing a system model that is capable of accurately representing rail infrastructure and topology, as a structural aspect, and train traffic rules and signalling rules to capture behavioural aspects. This would need to be completed to ensure that both
models exhibit a reasonable degree of accuracy, in order to be practically applicable, but must also be simple enough to allow for fast processing performance.

Once this foundation has been developed and implemented as a workable model, process models would then be introduced to allow problems to be solved through computed advice. The types of problems considered are those that are typically associated with causing or amplifying disturbances that can potentially lead to severe delays. As mentioned on several occasions, the process models that we aim to develop are those that suggest a solution that can potentially minimise the delay. A thought at this point, is to consider several solutions to be considered and presented in order of viability – i.e. most viable through to the least viable – with adequate justifications on how such a solution was determined. This would ensure that rail operators are suitably empowered with the ability to make the final decision, since we consider it as a fundamental requirement for humans to be the final decision makers. The system must assure the operators that the solutions presented are workable and can reduce the delays, which is why solutions that do not satisfy all of the safety constraints that we define are simply ignored.

We have identified methods form artificial intelligence as a means for developing and optimising our strategies in developing a final end solution, where we intend to create a rule based expert system that is capable of realising our goals. The majority of future plans will involve gaining understanding as to how we may represent the system model, where currently multi-agent orientation appears to be the most viable option, as well as various algorithms that may be applied or developed further to establish solutions to scheduling, conflict resolution, dispatching and delay optimisation problems, which are all concerned with the process aspect of rail network. We intend to begin by solving these problems on a microscopic level, where the case study of Swindon station has been considered and eventually other case studies of other station are likely to follow. We presume that a macroscopic perspective can be achieved through a collection of microscopic representations as trains iterate through different areas, although such considerations are currently beyond the scope of our work. Essentially, artificial intelligence and the development of a knowledge base, we believe, will allow for the development of a powerful and fully optimisable system, based on process models that are concerned with the operations of trains and are established upon the principles defined by the system model. However, NP-completeness is an issue that would need to be taken into consideration and that the representation must be simplified enough to potentially overcome this, though this will present a persistent challenge throughout the duration of our work.

In terms of processing capabilities, it would be difficult to design a large and powerful solution strategy that can be computed in real time. Therefore, methods must be investigated to determine how our solution can be optimised to allow for real time performance. This may initially be achieved by executing the overall system using a GPU, although this may present serious limitations. Other methods can include parallel processing, integration of cloud computing resources or even to optimise the algorithms to allow for execution in polynomial time. We will determine which method is most suitable after we first realise what solution strategy would allow the generation of accurate, relevant and useful advice, which can then optimised further to allow for real-time performance. For now, parallel processing over multiple GPUs first appears to be most viable option, although, as we proceed through our investigation, there will several opportunities for this hypothesis to be tested and ultimately utilised to form the very final stages of a workable system. It may be that current computational resources may not allow for the final development and execution of a final system, but as computing resources develop in their capabilities, it may eventually be possible to allow the system to perform in real time.

As a final note, this paper has presented the structure of our work in terms of what we plan to do to realise our short and long term goals and how we, at an initial level, intend to achieve these. Other papers, publications and eventually a final thesis documenting our work will soon follow.
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REFERENCES


[12] Information available at http://www.networkrail.co.uk/