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Optimizing the Rail Operations from Mine to Port

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ABSTRACT

The Rail Scheduling Tool (RST) is a tool to facilitate the planning and scheduling of train operations which was developed by Optym Private Limited to provide solutions for the BHP Billiton Iron Ore supply chain. BHP Billiton is leading company in mining industry which needs solutions for its different rail operations to carry out rail operations smoothly and efficiently. Multiple parameters like maintenance, break down, congestion in rail network, speed restriction etc. has to be taken into consideration when providing solutions to such problems. RST is a planning system as it's used for weekly, daily and hourly planning. It is a real time system as it uses real-time data for generating predictions. It is a business critical system, as if it stops working BHPB rail operations will be affected which is critical to their operations. This paper describes how the application intelligently handles different parameters of the iron ore supply chain and generates optimal predictions for the future movements of trains from mine to port. This application provides optimal solution by using the available resources efficiently and by reducing the congestion in the rail network.

INTRODUCTION

RST generates detailed train route predictions for a given train departure template while considering maintenance of tracks, car dumpers and loadouts, speed restriction, switch clamping, meet-pass planning, acceleration, deceleration of the train, etc.Key features of this application include (a) multi-user, multi-scenario and multi-monitor system. (b) High quality visual application that presents data in an easy to understand format. (c) Quick response time. (d) Allows users to review and analyse their changes in a sandbox before publishing. (e) Train graph displaying past and future train movements with several useful features.

1.1. Overview of BHPB Operations:

Most of the iron ore produced in Australia is exported to other countries (mainly China). Same is true of BHPB IO(Iron Ore). Iron ore is exported through ships. Port Hedland is a natural deep anchorage port in North Western Australia which is perfect for shipment of the iron ore. Almost all the iron ore mined in Australia is exported through this port. The port facility consists of two harbors: Nelson Point (NP) and Finucane Island (FI). BHPBIO (BHP Billiton Iron Ore) also uses Port Hedland for exporting their iron ore. BHPBIO mines are located in Pilbara region of Western Australia which is about 400-500 km inland of Port Hedland. The iron ore is moved by railway lines from mines to Port Hedland area. Trains get loaded with ore at mines, and get empty at the port. Trains runs loaded from mines to port and return back empty.

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1.2. Background and Need for Rail Roads:

Most of the iron ore produced by mining companies is exported to other countries. Iron ore is usually exported through ships; thus, they need a port with natural deep anchorage. Usually mining areas are located 400-500 km inland of port, which generates the need for moving large quantities of iron ore from mines to port. Large mining companies construct their own rail network to move ore from mines to port so that they have better control on the supply chain.

II. Overview of rail network and its operations:

Fig.1. shows the overview of the Rail Network. The Terminals marked with red color border in the fig.1. are the regions of mines. Loaded Trains move from mine to port. At port car dumpers are used to unload the mines. Trains passing through the Mainline Track are called Mainline trains and trains passing through Single track are called Shuttle Trains. Loaded trains pass through West Track and Empty trains pass through East Track.

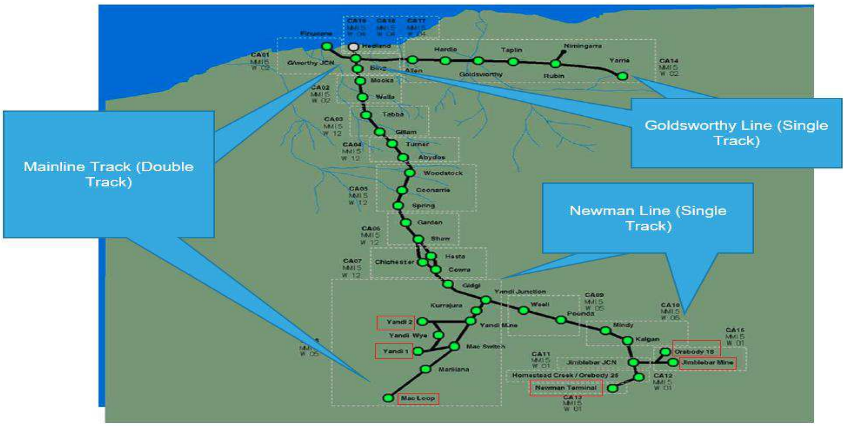

Fig. 1: Overview of BHPB Rail Network

Some of the useful terms used in Rail Operations are described below:

Cars: This is the term used to indicate the bogies of train.

Rakes: Train is divided into rakes. Mainline Train is divided into 2 rakes. Each rake consists of 132 cars.

Car Dumpers: Car Dumper is a mechanism used for unloading the mines from the cars. Car dumper takes a section of the track with the car and rotates it to unload the car. Before going to car dumper the rakes get separated at split location and go to different car dumpers for faster processing.

Loadouts: At mines the trains get loaded. These locations are named after the mines they have. The loadouts are Yandi 1, Yandi 2, Mac, Newman, Jimblebar, OB18, OB24.

2.1. Types of Mines and Iron Ore product mix:

Based on the iron content and the size, iron ores are categorized into multiple product categories. Size based category: Lumps (6-33 mm) and Fines (<6 mm). At BHP, followings are these categories: Newman Lump, Newman Fines, MAC Lump, MAC Fines Yandi Fines. At mines, trains move at the speed of 3.5 kmph through loading tunnels. Cars are loaded using clamp scoops from the top. All trains out of Yandi mines should be Direct Saleable Ore. Cars are partly loaded at Yandi 1 and then at Yandi 2 to achieve right grade in a loaded car. Shuttle trains move between mines to take iron ore to Newman crushing plant.

2.2. Network Capabilities: Trains and Ports:

Trains: BHPB operates 450 kilometer of track that connect mines to ports. Most of the rail network is double track. Some part of the network that carries less traffic volume is single track. 17-18 trains per day in each direction. System runs 24 hours per day, 365 days in a year. Each train needs 4 locomotives. Each train carries 2 rakes of 132 railcars each; thus, carrying 264 cars. Each railcar has a tare weight of about 25 tons and carries about 125 tons of iron ore. Thus, a loaded car has a weight of about 150 tons. Each train carries 30,000 tons of iron ore. BHPBIO is currently producing 180 – 190 million tons per annum (Mtpa) of iron ore. Shuttle trains running between mines carry 67 cars per train and are powered by two locomotives. A rake in a train contains only one product type. *Ports:* Port Hedland is world’s second largest iron-ore port after Sao Luis in Brazil (Vale’s ore export point).The port facility consists of two harbors: Nelson Point (NP) and Finucane Island(FI).There are three car dumpers at NP and two (including one to be commissioned) at FI. Each dumper can unload 50 mtpa ore.Currently, 36-37 (sample distribution - 22 NP, 14 FI) rakes are unloaded every day.

Each harbor has four berths to load ships and one reclaimer. An underwater tunnel between NP and FI enables ore transportation from NP to FI. Around 60% of ores are dumped in stockpiles and rest is directly loaded into ships. Most of ships carry two products. Though some ships can carry either one product or more than two products as well. The loading time per ship is around 36 hours. Most of operations at the port are automated: car dumpers, reclaimers, conveyor system, etc. The automated system moves a rake from the yard to dumper and then to yard in around 2.5 hours. Each railcar is equipped with rotary coupling. The ore carrying capacity of the conveyor belt system is 10-12K tons per hour. Loaded ships depart from the harbor at high tides. The channel from harbor to ocean is 42 km long and it takes 3 hours for ships to travel. Lump products go through rescreening plant before being loaded in ships.

III. Optimization and its challenges:

In [1], authors have explained about the integrated supply chain. Iron Ore supply chain starts from extracting, processing, loading into rails, unloading at ports and finally shipping to other counties using ships. Many operations and processes are involved in the integrated supply chain from mine to ship. Our application only focuses on the operations to be carried out between the mine and port. Before providing the solution we need to understand the challenges and business needs while optimizing the rail network. Planning and Execution are the two important business processes that govern the material movement. Planning is a process that deals with planning and scheduling of different parameters that are involved in the mine moving process. We focus on short term as well medium term planning. Short term planning is done for future 7 days and medium term planning is done for future 35 days.

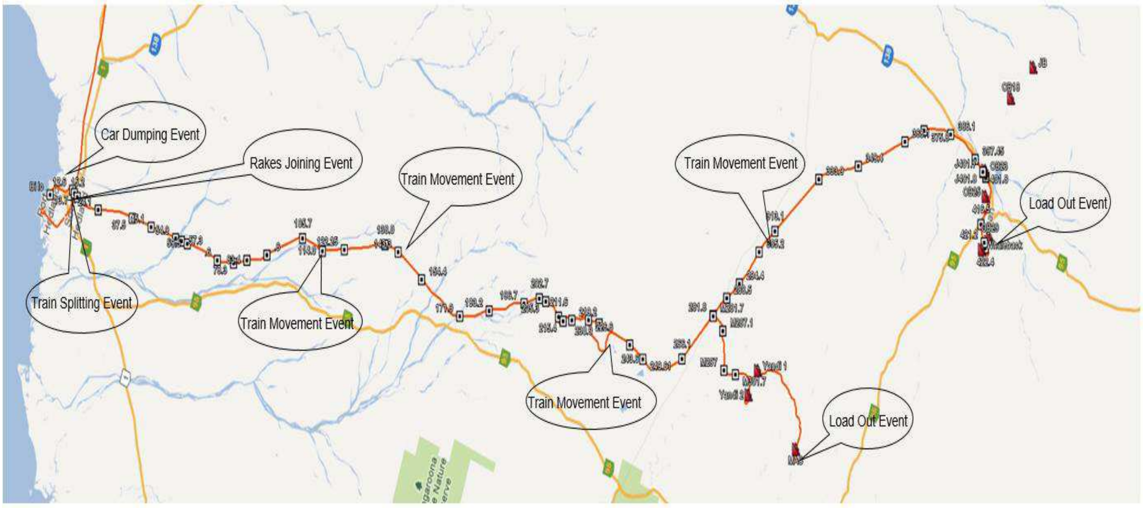

Fig. 2: Various events in the Rail Network

Planning consists of scheduling of departure times of the trains, Rail Maintenances, End Facility maintenances and the type of mine it should carry. There are many other parameters which should also be considered like crew changeover, speed restrictions etc. Tracks and the switches on the tracks need timely maintenances. These will be planned and executed under the rail maintenances. Similarly, maintenance of car dumpers and loadouts can be categorized under end facility maintenances.

Fig.2. shows different events that are part of the rail network. The following are the events which take place in rail network:

- *Load Out Event:* This is the event where the loading takes place.
- *Train Movement Event:* Loaded/Unloaded travel through the rail network.
- *Rakes Spitting Event:* Before going to the car dumper, the rakes of the train split at the specified location.
- *Car Dumping Event:* Loaded trains are unloaded at the car dumpers.
- *Rakes Joining Event:* Once trains finish loading they join again at the specified location.

Another issue in designing the solution is the weather condition. There might be unexpected deviations in the weather condition which may result in disturbances for the movement of the trains. Because of these deviations and disturbances the schedule that is released for execution can be rendered inefficient or even infeasible. This gap between scheduling and execution is a major drawback in many commercial or custom-made applications that results in a rigid scheduling which is not agile enough to respond swiftly to disturbances in the supply chain. Meet and Pass is one of the challenges which have to be addressed very carefully for the optimal solution. It is a technique where train has to be intelligently guided when one track is engaged or under maintenance or it is blocked because of certain reason. For example, if there is track maintenance at West Track at certain point then the train passing through the West Track has to change its direction and use the East Track. Before moving to East track it should check whether there is any train on that track at nearby location. Also, once the maintenance location is crossed it should switch back to the west track again. This check has to be performed in the entire network after planning and before the execution of the plan.

IV. Solution approach and Implementation Business Objectives:

The scope of the RST project is to build a flexible, fit for use rail scheduling tool that enables IROC (Integrated Remote Operations Centre) schedulers to maximise capacity when moving iron ore from mines to dumpers in a timely manner. Business requirements include option to configure rolling stock consist and user inputs, managing track possession, generating real time active schedule ETAs (Estimated Time of Arrivals), accounting for TSRs (Temporary Speed Restrictions) and PSRs (Permanent Speed Restrictions), Planned Maintenance, and Meet - Pass planning. The tool should provide Train Graphs for visualizing and analysing model outputs. Also, the tool should have the ability to populate downstream systems such as Rail Historian.

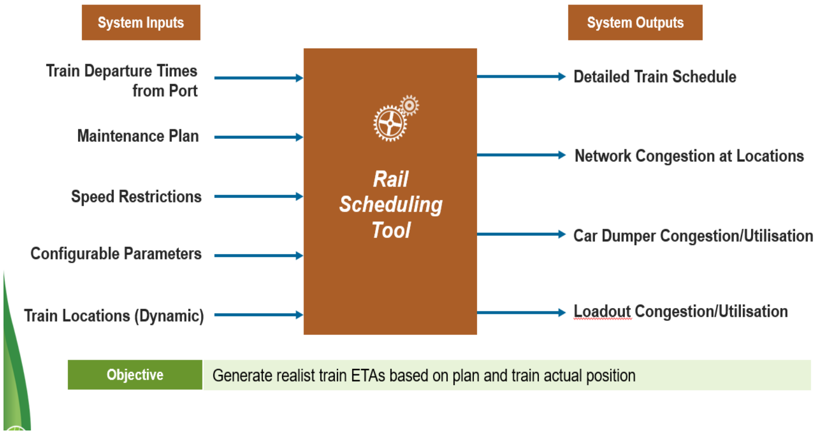

Fig. 3: RST High Level Functional Diagram

Fig.3. shows the High Level Functional Diagram of the Application.RST R1 engine will be responsible to create the detailed route of the train by taking the baseline train schedule (planned train departures, and planned train destinations) as input. Detailed route of train includes the arrival and departure time of train at each track section in its route. The part of the application which generated the optimized result is known as engine. RST engine is based on an Operations Research technique called as “Discrete Event Simulation”. In this technique, system operations (train movements) are represented as a chronological sequence of events. Each event (train movement) occurs at an instant in time and marks a change in the occupancy of the resources (track segments). The simulation will have warm-start based on real time status of trains, rakes, car dumpers and load outs.

4.1. RST Algorithm modules:

The RST algorithm is architected in a very modular manner. Below are the major modules of the RST algorithm:

Meet-Pass Planning and Deadlock Detection Module: This module uses network optimization techniques to generate an efficient meet-pass plan. This module also ensures that there are no train conflicts (deadlocks) in the generated solution.

Routing Engine Module: This module is responsible for generating detailed train routes while accounting for the availability of tracks and other resources.

Data Access Layer and Reporting Module: This module is responsible for accessing all of the data and generating reports for output.

The RST algorithm uses a relatively simple logic for the meet-pass planning of trains. Fig.4. shows the high level design of the meet and pass algorithm. It uses the priority rule based logic to resolve train conflicts. It also ensures that no deadlocks are created through its meet-pass decisions. Since it performs a very detailed simulation of train movements, we have kept the logic simple, as adding optimization within such a detailed simulation would make it too time-consuming to be done in near real-time.

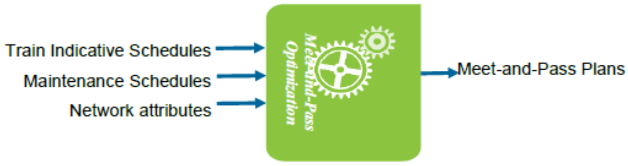

Fig. 4: Meet-Pass High Level design

4.2. Overall flow of the Application:

To generate the detailed schedule i.e. when the train will reach the mine, when it will reach car dumper or the port, analyse the scenario. On Analysing application will start running the simulation engine. If the engine is already initialised reset it to default. If the engine is not initialized, then it will start creating the network. The engine will work on generating the potential paths for the trains. Once the potential paths are generated take the input parameters. Input parameters to the engine are trains and rakes current location, Current Trains Speed and Occupancy Info, Car-dumper & Load-out Status, Maintenance Plan and the Speed Restrictions.

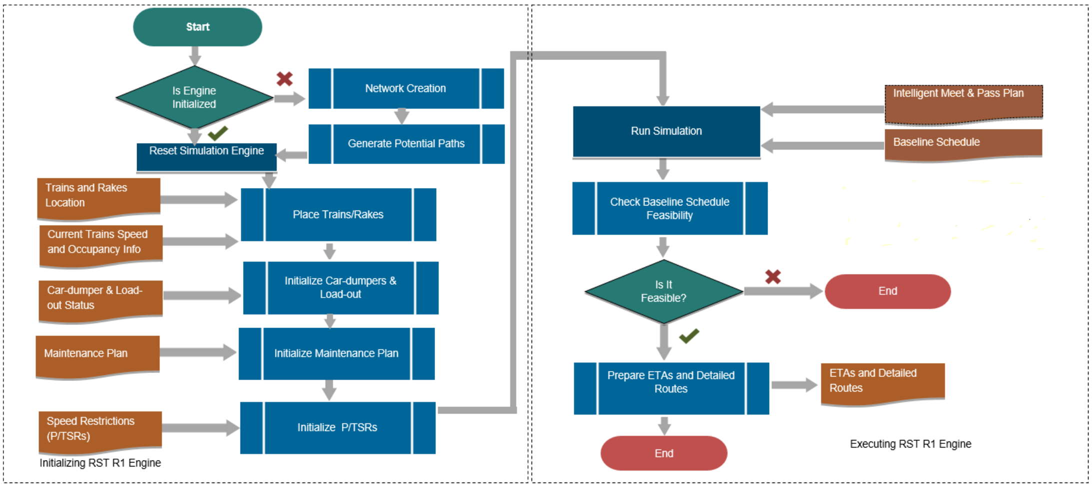

Fig. 5: Flow chart to Generate Detailed Schedule

Fig.5. describes the overall flow of the RST. Initialize these parameters and run the simulation engine. It will generate the detailed schedules for the trains. If the generated schedules are feasible then it is published and ETAs are prepared accordingly. If the generated schedule is not feasible then it is discarded.

Results:

As an important part of an application it provides the visualization component to view the movement of trains. The visualization component is known as Train Graph and it shows both the actual and predicted movement of the trains. Along with the train movements it shows all the other entities which affect the train movements like rail maintenances, speed restrictions, switch clamping. Visualization also consists of the manual dwell and manual split icons represented on the Train Graph. This Train Graph is not read only it is also platform to make the necessary changes if required by the user. Fig.6. shows the window to add the rail maintenances. Modify pages are mainly meant to take input from the user and the analysed results are viewed from Analyse pages and the Train Graph.

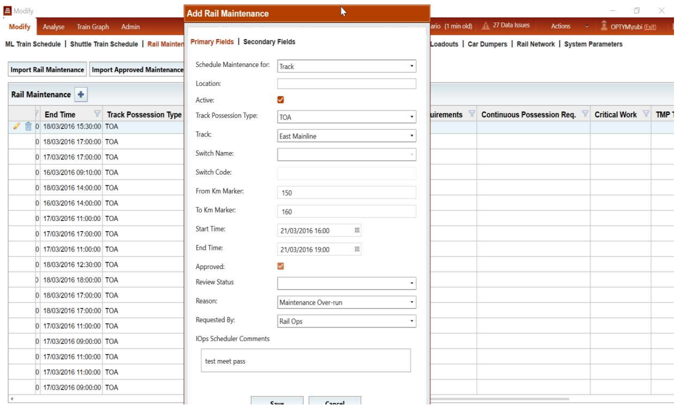

Fig. 6: Adding rail maintenances

Once the user is done with adding the necessary changes he can either keep the changes in sandbox or publish it to the production. Production is the real environment where the published changes have to be executed. Fig.7. gives the glimpse of the visualization. It represents the train lines moving from one location to another with time. As you can see the X-Axis represents the time and the Y-Axis represents different locations with the Kilo Meter markers in the rail network. Along with that, the user is also provided with option to view the train graph in different views and with different visualization effects. The user can customize the visualization as per his needs.

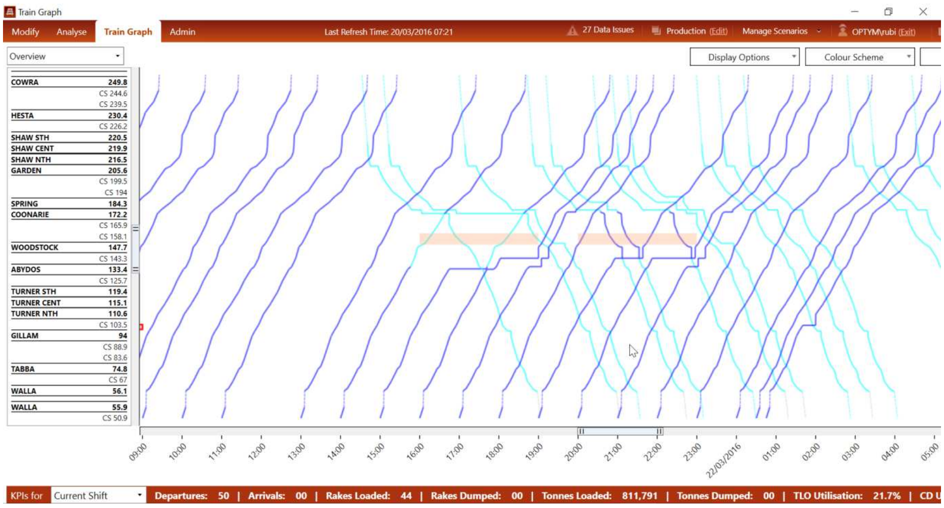

Fig. 7: Visualizing movement of trains using Train Graph

Train lines can be represented based on the product colour or the track colour. Light blue colour represents the West track whereas dark blue represent East track. It can be seen from the fig.7. that when there is maintenance on east track, trains travelling on east track are switching to west track and once the maintenance is over they are switching back to their normal track. Same behaviour is exhibited in case of another maintenance on west track.

VI. Conclusion and Future Work:

In this paper we developed a tool to optimize and plan the rail operations using different algorithms. RST takes the input parameters and generates the output using simulation driven algorithm. RST generates detailed schedule based on many parameters like maintenance plan, Speed Restrictions, Train Locations, Train Departure Times from port and mine and other configurable parameters. RST also generates potential route for the trains by running the optimisation engine. Output of the engine can be viewed in the Analyse pages and train movement can be viewed using the Train Graph generated by the RST. RST provides facility to plan rail operations on daily, weekly and monthly by giving option to create different scenarios and analyse those. Going forward RST can display data issue messages related to the congestion because of the blockage in the network due to various factors such as switch clamping and track maintenance for long time. Many more features can be added or enhanced as per the custom needs since it is a flexible application.

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