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Evaluating the Use of Operational Management Techniques for Capacity Improvements on Shared-use Rail Corridors

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16. Abstract

The majority of intercity passenger and commuter rail services in the United States (U.S.) operate on the shared-use corridors with freight rail services. These types of operations tend to be challenging for efficient capacity utilization and reliability due to the high heterogeneity of trains (diversity of trains operations). In addition, the projected growth in demand for rail transportation is likely to exacerbate the situation, making efficient use of capacity a necessity for freight and passenger traffic alike. There are two main approaches to improve the capacity levels, either by applying new capital investment or by improving operational characteristics and parameters of the rail services (such as improving the trains timetables). To date, U.S. has concentrated more on the first approach while the second approach is commonly used in European practices. It would be beneficial to evaluate the main challenges and advantages of using operational management techniques to improve the capacity utilization along shared use corridors in the U.S.

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Table of Contents

List of Figures

List of Tables

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EXECUTIVE SUMMARY

This research investigated the use of operational management techniques to improve the capacity utilization and/or level of service (LOS) parameters along shared-use rail corridors. Two case studies were used for the research; the multiple-track Washington, DC –Baltimore, MD section of the Northeast Corridor (NEC) and the currently single track Detroit – Jackson segment of Michigan accelerated rail corridor. The research tools included three commercial railway simulation packages – Rail Traffic Controller (RTC), RailSys, and OpenTrack – as well as a new analytical rescheduling model, Hybrid Optimization of Train Schedules (HOTS).

Chapter 1 of this report explains the background of the research, including a review of railway capacity and respective methodologies and tools available for its evaluation. The review revealed that there is no single definition of railroad capacity and that various techniques, tools and metrics can be used to evaluate the capacity based on the objectives, operational characteristics and the scope of the given study. There are several differences between various global rail systems that affect the approaches, tools and outcomes of capacity analysis, including structured vs. unstructured operations philosophy. The chapter also introduces the rail simulation tools, the HOTS model, and briefly explains the operational management techniques, particularly rescheduling, used to improve capacity utilization or LOS parameters.

Chapters 2 and 3 introduce the case studies selected for the research and data requirements for the analysis. Both case studies required similar data (infrastructure, signaling, rolling stock, and signaling system), but each case contained different characteristics and specifications. The research team was provided with the initial database for both case studies in RTC format, which were then replicated in RailSys/OpenTrack for the rescheduling and rerouting analysis. Chapter 3 explains the replication process and describes the research methodologies that used both combined simulation and the analytical HOTS model to optimize and test various alternatives.

Chapter 4 presents the rescheduling scenarios considered for the NEC and Michigan case studies. Three scenarios were defined for each case study. The initial schedule (Scenario 1), considered as the "current situation", was the benchmark for evaluating the other scenarios. Scenarios 2 and 3 applied simulation tools and HOTS model to modify the schedule from Scenario 1. In the NEC scenarios, the effects of directional/non-directional operation patterns on capacity and LOS parameters were investigated by converting the non-directional pattern (initial schedule) to fully directional operations. Schedule deviation, dwell time and minimizing overtaking were used as evaluation criteria. The NEC Scenario 2 that used a heuristic approach performed better than Scenario 3, conducted through HOTS model, but it was also significantly more time consuming and iterative runs of HOTS might have aligned results more closely. In Michigan case study, Scenarios 2 and 3 were developed to evaluate the addition of new freight (Scenario 2) and new commuter train services (Scenario 3) to the initial schedule while maintaining existing infrastructure. HOTS model was used for rescheduling which allowed addition of eleven new freight and ten commuter services in Scenarios 2 and 3, respectively, while requiring only minor schedule changes for existing trains. The Case Study Scenarios and Results table below summarizes the objective, methodology, and results of all conducted scenarios.

Table - Case study scenarios and results

Case Study	Scenario	Objective	Methodology Approach	Final Outcome
NEC	**1- Initial schedule**	**To provide a benchmark schedule**	Combined Simulation	Replicated schedules in RailSys and OpenTrack
	2- Heuristic scenario	To develop a fully directional pattern **heuristically**	Combined Simulation	Successfully converted to fully directional operations (time consuming approach, required expertise and construction of island platforms at selected stations)
	3- HOTS scenario	To develop a fully directional pattern using **"HOTS model"**	Combined Simulation + HOTS model	Successfully converted to fully directional operations (quicker and more convenient than Scenario 2, required construction of island platforms and overtaking at stations)
MI	**1- Initial schedule**	**To provide a benchmark schedule**	Combined Simulation	Replicated schedules in RailSys
	2- Adding freight trains scenario	To add **"new freight trains"** to the initial schedule	Combined Simulation + HOTS model	11 new freight trains successfully added to the service
	3- Adding commuter trains scenario	To add **"new commuter trains"** to the initial schedule	Combined Simulation + HOTS model	10 new commuter trains successfully added to the service

When applying rescheduling and timetable management techniques in future research opportunities, the following factors should be taken into account:

- Using various simulation tools through combined approach of rescheduling is effective, but also time-consuming and requires certain level of expertise on each tool.
- HOTS model can facilitate the simulation procedure for rescheduling and requires less user expertise than the combined simulation approach. However, several iterations and adjustment of the user-defined parameters, such as min/max allowed dwell time, may be needed to provide comparable results with heuristic methods.
- Timetable changes and rescheduling to improve the capacity utilization may increase the risk of traffic congestion and train delays, if recovery time is not considered in the new schedule.
- Incorporating the uncertainties of the daily operations and considering the network impact from rescheduling can provide more robust and reliable schedule and reduce the risk of service interruptions.
- Several parameters can affect the results of rescheduling, but the following parameters seem to have higher impact:
  - Schedule changes (average schedule deviation, stop pattern and dwell time)
  - Maximum track occupancy level (in peak hours) as it can identify the bottlenecks of the corridor
  - Train delays before and after rescheduling

PROJECT INTRODUCTION

Project Title: Evaluating the Use of Operational Management Techniques for Capacity Improvements on Shared-use Rail Corridors

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Project Objectives: The objective of this research is to use rail operations simulations to investigate operational management techniques as an alternative to capital infrastructure investments to improve the capacity utilization and /or LOS parameters along shared-use rail corridors. In addition, it compares the dependability of structured versus improvised (or unstructured) train operations on the corridors.

Project Abstract: The majority of intercity passenger and commuter rail services in the United States (U.S.) operate on shared-use corridors with freight rail services. Share-use corridors present challenges for efficient capacity utilization and reliability due to the high heterogeneity or diversity of trains and train operations. The projected increase in demand for rail transportation is likely to exacerbate the situation, thus making efficient use of capacity a necessity for freight and passenger traffic. Improved capacity levels are reached by new capital investments or by improving operational rail service characteristics and parameters, such as improving train schedules to allow for more efficient use of the infrastructure. To date, U.S. has concentrated more on the infrastructure improvements, while European rail system commonly investigates the operational characteristics. It would be beneficial to evaluate the main challenges and advantages of using operational management techniques to improve the capacity utilization and/or level of service (LOS) parameters along shared use corridors in the U.S.

This study investigates the use of operations management techniques, in particular using rescheduling practices on selected shared use corridors. The corridors used in this study are Detroit – Jackson section of the Michigan accelerated rail corridor and Baltimore-Washington section of the Northeast Corridor (NEC). The study methodology uses a combined simulation approach of applying two European simulation packages (RailSys and/or OpenTrack) in addition to a common U.S. focused simulation package, Rail Traffic Controller (RTC), to evaluate different traffic scenarios and operational variables at the selected locations. The study also uses hybrid optimization of train schedules (HOTS) model, developed by the research team, to facilitate rescheduling practices available in commercial simulation tools.

This report addresses each of the five tasks defined in the research proposal. Chapter 1 reviews the concept of capacity, its methodologies/tools, and compares the main parameters and characteristics of the U.S. and European rail networks. The chapter also introduces the rail simulation tools, the HOTS model, and briefly explains the operational management techniques used to improve capacity utilization or LOS parameters, particularly rescheduling. Chapters 2 and 3 present the case studies selected for this research, describes the research methodologies and explains how the case study databases are duplicated and used in the different simulation tools. Three main scenarios are defined for each case study and various capacity and LOS parameters are analyzed. Chapter 4 presents more details about scenarios and discusses the results of the research. Chapter 5 summarizes the research findings and provides recommendations for future research opportunities.

TASK 1- REVIEW OF CAPACITY

1-1 Introduction

The majority of passenger rail services in the United States (U.S.) operate on shared-use corridors with substantial freight rail services. Passenger/freight traffic may each operate on dedicated tracks, but in most cases, all trains share the same track infrastructure [1, 2]. The high utilization corridors in Europe carry intercity passenger, commuter, freight and sometimes, high-speed passenger service on shared tracks. Most European train movements follow a predefined schedule with structured daily timetables that are planned as much as a year in advance. Even though passenger trains have regular schedules in the U.S. as well, the prevailing operations pattern for shared corridors follows an unstructured (improvised) philosophy where train schedules and routings, especially for freight trains, are often adjusted on a daily or weekly basis [3].

In general, there are two main approaches to improve the capacity levels, either by infrastructure investments, or by adjusting capacity utilization or LOS parameters through operational changes. In either case, modeling and/or optimization techniques can be used to evaluate the effects of either approach. Past capacity analyses in the U.S. have concentrated on infrastructure improvements, while European analysis often focus on rescheduling and timetable management to identify beneficial operational changes. The current efforts to develop shared-use corridors with prevalent, higher speed passenger services in the U.S. suggests some of the European operational management techniques might provide benefits to U.S. capacity studies.

1-2 What is Capacity?

1-2-1 Capacity Concept and Definitions

The definition used for rail capacity in the literature varies based on the techniques and objectives of the specific study. In Europe, the most common method for capacity analysis is provided by the International Union of Railways (UIC) code 406. According to UIC 406, there is no single way to define capacity and the concerns and expectations vary between points of view of railroad customers, infrastructure and timetable planners, and railroad operators [4]. In the US, some examples used in past capacity analysis include Barkan and Lai, who defined capacity as "a measure of the ability to move a specific amount of traffic over a defined rail corridor with a given set of resources under a specific service plan, known as level of service (LOS)". They listed several infrastructure and operational characteristics which affect capacity levels, including length of subdivision, siding length and spacing, intermediate signal spacing, percentage of number of tracks (single, double and multiple-tracks), heterogeneity of train types (train length, power-to-weight ratios) [5]. Another definition was provided in a capacity modeling guidebook for the U.S. shared-use corridors, released by Transportation Research Board (TRB) in 2014. According to this guidebook, railway capacity is defined as “the capability of a given set of facilities, along with their related management and support systems, to deliver acceptable levels of service for each category of use.” Similar to the other capacity definitions, different parameters and variable should be taken into account during capacity analysis including train dispatching pattern, train type and consist, signaling system, infrastructure and track maintenance system, etc. [6].

The literature categorizes the main metrics of capacity level measurements into three groups:

- Throughput (such as number of trains, tons, train-miles),
- Level of service (LOS) (terminal/station dwell, punctuality/reliability factor, and delay)
- Asset utilization (velocity, infrastructure occupancy time or percentage) [7].

The Federal Railroad Administration (FRA) recommended “hours per 100 train-miles” as a delay unit (a capacity metric) to measure the amount of delay trains may face in the U.S. [8]. in Europe, the rail operators typically use throughput metrics (number of trains per day or hours) to measure the capacity levels, although punctuality and asset utilization metrics are also applied as secondary units [9, 10]. More details about capacity definition and its specifications have been discussed in a paper by Pouryousef, Lautala, and White [11]. This research uses the throughput metric number of trains per day and asset utilization (track occupancy level) as its main capacity measurements.

1-3 Differences-between the U.S. and European Rail Systems

The U.S. and European rail networks have several similarities, such as mixed operations on shared-use corridors, and using modern signaling and traffic control systems (e.g., developing ETCS in Europe and PTC in the U.S.). On the other hand, significant differences also exist that affect the preferred methodologies, tools and the outcomes of capacity analysis, as well as overall level of capacity utilization. Figure 1 highlights several key differences between infrastructure, signaling, operations and rolling stock in Europe and the U.S., followed by a brief discussion of each criterion. A more comprehensive discussion of the topics is provided in a paper by Pouryousef, Lautala, and White, 2015 [11].

	The U.S. Rail Network	**Europe Rail Network**
Infrastructure	**Private ownership of rail infrastructure** **Bidirectional double-tracks / single track** **Longer sidings/yards** **Higher axle loads** **Many existing grade crossings**	**Public ownership of rail infrastructure** **Directional double-tracks** **Shorter distance between sidings/yards** **Larger radius horizontal curves**
Signaling	**Few corridors still under manual block operation**	**Majority of corridors under signaling systems** **Cab signaling & automated train stop aspects**
Operations	**Freight traffic (Majority)** **Unstructured operations pattern**	**Passenger traffic (Majority)** **Structured operations (freight, passenger)** **Higher punctuality for passenger and freight trains (short delays)**
Rolling Stock	**Longer and heavier freight trains** **Diversity of freight trains**	**Faster and more modern passenger trains (HSR)** **Diversity of passenger trains**

Figure 1 - The main differences in the U.S. and Europe rail systems [11]

1-3-1 Infrastructure Characteristics

- **Public vs. Private Ownership of Infrastructure**: More than 90% of the infrastructure is owned and managed by private freight railroads in the U.S., while in Europe almost all infrastructure is owned and managed by governments or public agencies. [8, 12]

- **Single vs. Double-Track:** More than 46% of rail corridors in Europe are at least double-track [13, 14], while approximately 80% of the U.S. rail corridors are single-track. [2, 8]
- **Directional vs. non-directional:** Most of the U.S. double tracks operate in non-directional (bidirectional) fashion and use crossovers along the corridor, while directional operation with intermediate sidings and stations is the common approach in Europe. Based on literature, the directional pattern of operating a given double- (multiple) track corridor can provide up to 25% more capacity in comparison to the non-directional pattern of operations. [8]
- **Distance between Sidings:** The distances between stations and sidings in the European rail network are generally shorter than in the U.S.
- **Siding Length:** Siding/yard tracks in the U.S. are typically longer than the European rail network, but in many cases are still not sufficient for the longest freight trains operating today. [12, 15]
- **Track Conditions:** Typically, railroad structure in the U.S. is designed for higher axle loads, but has tighter horizontal curves (smaller radius) and lower maximum operational speed than the European rail network. [12, 15]
- **Grade Crossings:** There are approximately 227,000 active grade-crossings along the main tracks in the U.S. [16, 17], while there are few grade-crossings on the main corridors in Europe, mainly due to higher train speeds. [18]

1-3-2 Signaling Characteristics

- **Manual blocking vs. signaling systems**: Manual blocking is relatively common on lower density corridors in the U.S., while In Europe, most shared-use corridors are equipped with one of the common signaling systems.[19]
- **Cab Signaling:** Implementation of automatic signaling systems such as ETMS and ATS is limited in the U.S., in comparison to the extensive use of such systems in Europe. [12]

1-3-3 Operation Characteristics

- **Improvised vs. Structured Operation:** While some specific freight trains (mainly intermodal) have tight schedules, the U.S. operations philosophy is based on the improvised pattern (unstructured) with no long-term timetable or dispatching plan. In Europe, almost all freight and passenger trains have a regular schedule developed well in advance, known as structured operations. [20]
- **Freight vs. Passenger Traffic:** The majority of U.S. rail traffic is freight while the majority of European rail traffic is passenger rail. [8, 21]
- **Delay vs. Waiting Time:** Delay (deviation of train arrival/departure time from what was predicted/planned) is more commonly used in the U.S. capacity analysis as the main performance metric, while it is limited in Europe to the events that are not predictable in advance [20].
- **Punctuality:** The punctuality criteria of trains are quite different in the U.S and Europe, since in Europe an on-time train arrival has much shorter deviation period from the schedule than in the U.S. punctuality concepts (e.g. 5 minutes in Europe vs. 30 minutes in the U.S.) [22-24].

1-3-4 Rolling Stock Characteristics

- **Train configuration (length and speed):** Typically, freight trains in the U.S. are longer and heavier than freight trains in Europe. From a speed perspective, the average speed of intercity passenger trains in Europe is significantly higher than in the U.S. [2, 12, 15]. Freight trains also typically operate on higher speeds and with less variability in Europe.
- **Diversity of Freight vs. Passenger Trains:** The U.S. rail transportation is more concentrated on the freight trains than Europe which has more diverse configurations in passenger side in comparison to the U.S. [2, 19]

1-4 Capacity Measurement, Analytical, Simulation and Combined Approaches

There are several different capacity analysis approaches and methodologies, but the input typically includes infrastructure and rolling stock data, operating rules and signaling features. The analytical (including parametric and heuristic) and simulation methods are the most common methods found in the literature, but a combined methodology, which takes advantage of both analytical and simulation methodologies, can also be applied for capacity evaluation. [11]

1-4-1 Analytical Approach

The **analytical approach** typically refers to any parametric, heuristic or mathematical expressions including optimization models to determine a solution for the respective problem. [25] The outcomes vary based on the level of complexity of the scenario and may be as simple as the number of trains per day, or a combination of several performance indicators, such as timetable, track occupancy chart, fuel consumption, speed diagrams, etc.

1-4-2 Simulation Approach

Simulation is an imitation of a system's operation, which should be as close as possible to its real-world equivalent. [25] In this approach, the process of simulation is repeated several times until the software achieves an acceptable result. The data needed for the simulation are similar to the analytical methods, but typically requires higher level of detail. **The simulation approaches** use either **general simulation** tools, such as AweSim, Minitab, and Arena [26, 27]; or **commercial railroad simulation** software specifically designed for rail transportation, such as RTC, MultiRail, RAILSIM, OpenTrack, RailSys, and CMS. [7, 25]

The commercial railroad simulation software can be classified in two groups; non-timetable based and timetable based. The main objective of non-timetable-based simulation is to automatically resolve any train conflicts. They are typically used by railways that operate based on an unstructured operation pattern without detailed long-term timetables, such as the majority of the U.S. rail corridors. Rail Traffic Controller (RTC), developed by Berkeley Simulation Software, is the most common software title in this category and used extensively by the U.S. rail industry. [7]

In the timetable based simulation software packages (typically used in Europe), train conflicts have already been removed in the initial timetable, so they have limited or no capabilities for automatic train conflict resolution. Instead, they use timetable management features, such as timetable compression technique to automatically adjust and/or improve the initial conflict-free timetable/schedule. The UIC's capacity approach is often one of the main theories behind timetable based simulation approach. There are several software packages in this category, such as RAILSIM (U.S.), OpenTrack (Switzerland), RailSys (Germany), and CMS (UK). [7, 25]

1-4-3 Combined (Hybrid) Analytical-Simulation Approach

In addition to the analytical and simulation approaches, a **combined (hybrid) analytical-simulation method** can also be used to investigate the rail capacity. A combined simulation-analytical methodology takes advantage of both methodologies' techniques and benefits and the process can be repeated until an acceptable set of outputs and alternatives is found. Parametric and heuristic modeling (in analytical approach) are more flexible when creating new aspects and rules for the analysis. On the other hand, updating the railroad component input data and criteria tends to be easier in the simulation approach, and the process of running the new scenarios is generally faster, although simulation may place some limitations when adjusting the characteristics of signaling or operation rules.

More details on analytical, simulation and combined (hybrid) methodologies of capacity evaluation, including review of several case studies in the U.S. and Europe that applied these methods can be found in a paper by Pouryousef, Lautala, and White, 2015 [11].

1-5 Operational Management Techniques

This study investigates applying operational management techniques as a method of improving capacity or LOS parameters. Various types of operational changes can be used to evaluate, but they are typically characterized as either:

- Changes in the train characteristics
- Train rescheduling and timetable improvement

The first type focuses on the train's physical characteristics and performance including the operational speed, total weight and length, and different patterns of loaded-unloaded movements (mainly freight trains). These types of changes may provide more efficient train operations, such as less number of dispatching in a day/week, or more homogenous operational pattern between trains. It should be emphasized that the more homogenous operation pattern typically allows higher capacity utilization than heterogeneous operations [10, 28, 29].

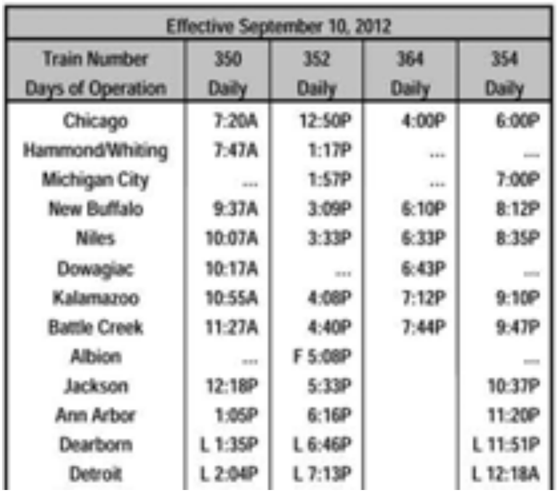
The second type of operational management techniques focuses on improving timetable (train schedule) and may include different parametric, optimization or simulation models and techniques. It can be applied for any corridor type, but is especially applicable for the shared-used corridors with significant number of intercity and commuter passenger trains, as (unlike many freight trains) they usually follow a predefined and detailed daily schedule. The objective may be to evaluate the potential capacity for future traffic, or to develop a higher quality of service for the existing traffic [28, 30].

This project focused on rescheduling and applying timetable management techniques using simulation or combined (hybrid) analytical-simulation methodologies. More details about timetable and timetable management techniques are explained in the following sections.

1-5-1 Review of Timetable/Stringline

"Timetable" demonstrates the schedule of all trains operated on a given corridor by presenting departure\arrival times of each individual train at each station/stop point (Table 1). [31] Timetable includes information about three main parameters of scheduling; 1) Train, 2) Time, and 3) Location (Station).

Table 1 - An example timetable for 2012 Amtrak service (Chicago-Detroit)



Effective September 10, 2012

Train Number Days of Operation	350 Daily	352 Daily	364 Daily	354 Daily
Chicago	7:20A	12:50P	4:00P	6:00P
Hammond/Whiting	7:47A	1:17P	...	—
Michigan City	...	1:57P	...	7:00P
New Buffalo	9:37A	3:09P	6:10P	8:12P
Niles	10:07A	3:33P	6:33P	8:35P
Dowagiac	10:17A	...	6:43P	—
Kalamazoo	10:55A	4:08P	7:12P	9:10P
Battle Creek	11:27A	4:40P	7:44P	9:47P
Albion	...	F 5:08P		—
Jackson	12:18P	5:33P		10:37P
Ann Arbor	1:05P	6:16P		11:20P
Dearborn	L 1:35P	L 6:46P		L 11:51P
Detroit	L 2:04P	L 7:13P		L 12:18A

Although a timetable is an informative tool for passengers or rail customers, a graphical representation of train movements, called "Stringline" (or "Graph diagram", or simply "Graph"), is more useful for rail operators and authorities to manage the train operations [28, 31]. A stringling is a time-distance diagram that essentially represents the same information as a timetable, but provides graphic illustration with the logical progression of trains on the corridor. This allows easier identification of potential train conflicts, meet/pass locations, etc. for dispatchers (Figure 2).

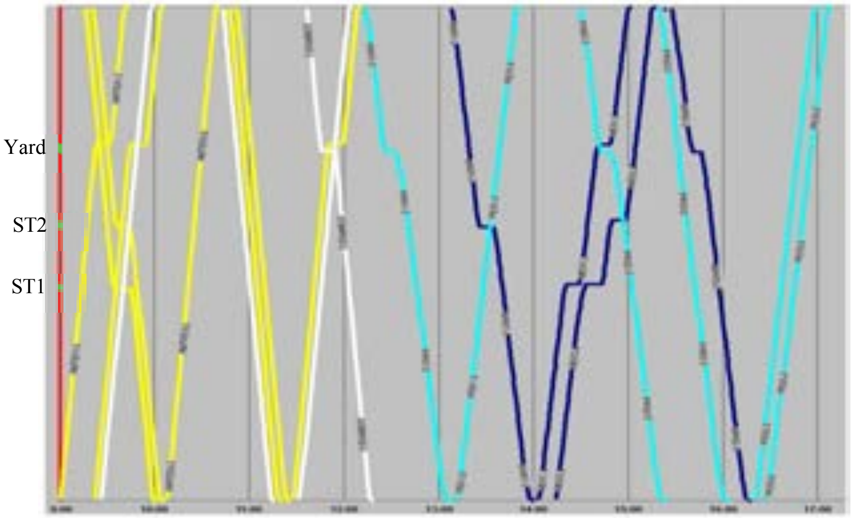


Figure 2 - An example of a stringline for a given single-track corridor

The horizontal axis of a stringline diagram typically refers to the “Time”, the vertical axis refers to the “Location” (or vice versa). Each individual line of the diagram represents an authorized train movement, including revenue trains, maintenance and inspection trains on the corridor. Train dispatcher can track the status of each individual train on the stringline and identify the direction and pace of moving trains (sloped lines) or stopped trains (at stations, yards or sidings) [6].

There are several rules related to the development of a timetable/stringline. One of the rules is to provide a **Conflict-Free** schedule where trains only meet (cross) each other at a legitimate stop point (station, siding, or yard). Any meets outside these locations on a single track corridor is interpreted as a conflict (Figure 3). Identifying and interpreting a conflict becomes more challenging on double or multiple-track corridor, since trains that use different tracks are shown in a single diagram. This may provide an illusion of a conflict when trains on different tracks meet each other (Figure 4).

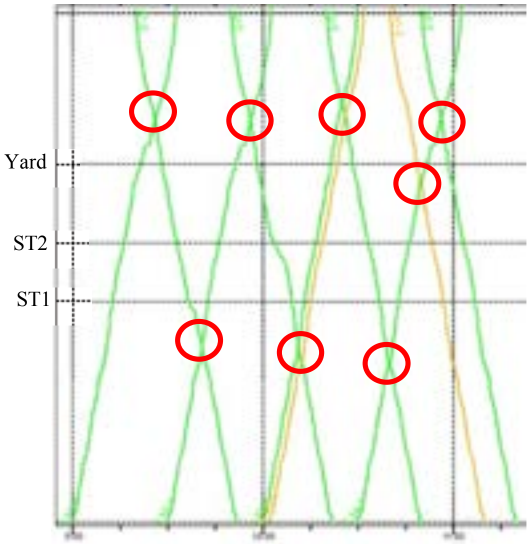


Figure 3 - Single-track stringline with several conflicts (highlighted with circles)

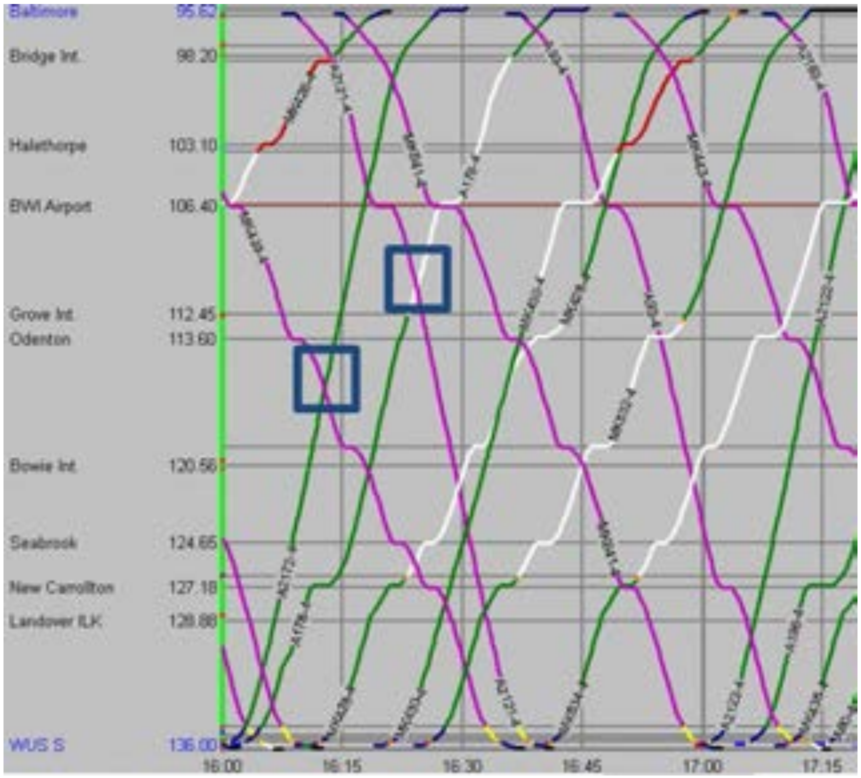


Figure 4 - Stringline for a given multiple-track corridor with train meets outside stations (different tracks used)

1-5-2 Timetable Compression Technique

Timetable compression technique is a way of rescheduling that can be completed by both analytical and simulation approaches. The method readjusts the operational characteristics of train service and is especially applicable for corridors with pre-scheduled timetables of all daily trains (structured operation pattern). A majority of European techniques and tools partially rely, on timetable compression technique.

The UIC's standard for evaluating and improving capacity (UIC leaflet 406, issued in 2004 and updated in 2013) is also based on the timetable compression technique [4, 10, 32-34].

Using the 2004 edition of UIC approach, the pre-scheduled timetable is modified by rescheduling trains to follow each other as closely as possible. Changes in the infrastructure or rolling stock specifications are not allowed during the process. In this process, modifications of the following are not allowed: travel times, crossing and/or station locations, or planned stops. Potential new slots on the timetable that are generated through compression can be dedicated for additional train service or maintenance activities [25]. Figure 5 provides an example of the timetable compression technique where an existing timetable along a corridor with quadruple tracks (Scenario a) is first modified by compressing the timetable (Scenario b) and then further improved by rescheduling (optimizing) the train order (Scenario c). As demonstrated in the figure, the Scenario c provides a higher level of theoretical capacity in comparison to the scenarios a or b [10].

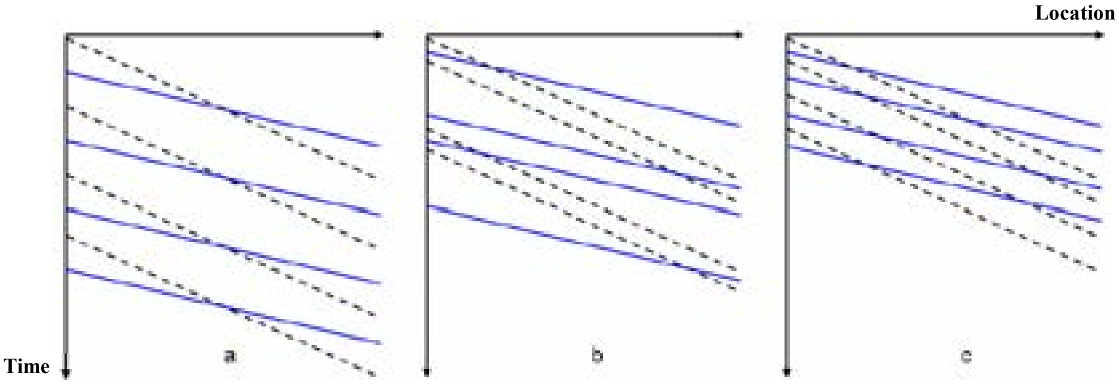


Figure 5 – (a) Actual timetable for a quadruple-track corridor, (b) compressed timetable with the same initial train order, (c) compressed timetable with optimized train order (chart layout follows typical European presentation. Solid and dot lines represent different types of trains) [10]

Typically, there are two approaches to reschedule and compress a timetable. The "same-order" approach maintains the departure train order based on the initial requested times, but the train order at arrival may differ from the initial schedule due to the compression and potential adjustments in stop patterns. The "order-free" (shuffle) approach departs trains based on user preferences, such as earliest possible departure time. Train order may be changed in both departure and arrival locations. Simulation and timetable management tools equipped with timetable compression techniques usually follow only one or the other approach outlined above. For example, the UIC compression technique (2004 edition) is normally based on same-order approach, such as the timetable compression technique available in RailSys [35]. Our research applies both same-order and order-free approaches in the case study scenarios.

1-6 Review of Capacity Tools Used in the Research

Two types of capacity evaluation tools were used in this research, commercial rail simulation packages, and an analytical-simulation tool developed by the researchers. The following sections explain the tool details in more depth.

1-6-1 Review of Commercial Rail Simulation Tools

Three commercial rail simulation packages – RTC, RailSys, and OpenTrack – were used at different stages of the study. RTC was launched in the North America's rail market in 1995 and has since been continuously upgraded to include a variety of simulation practices. The dispatching simulation component of RTC is based on a decision support core, called "meet-pass N-train logic". For any dispatching simulation practice, "meet-pass N-train logic" will decide the exact train arrival and departure time from different sidings, based on the defined train priorities and preferred times of departure. The simulation outcomes may include a variation between the simulated departure times and preferred times [36].

RailSys, developed in Germany by Rail Management Consultants GmbH (RMCon) is a timetable-based operation management software package that includes different tools for timetable construction/slot management, track possession planning, and simulation features. It is used predominantly in Europe and has been available since 2000. The capacity feature of RailSys uses the UIC code 406 which is based on the timetable compression technique [35, 37].

OpenTrack is another commercial simulation package widely adopted in Europe. It was initially developed by Swiss Federal Institute of Technology-Zurich (ETH-Zurich) and has been offered by OpenTrack Railway Technology Ltd. since 2006. OpenTrack can be classified as a timetable-based simulation tool that provides several simulation features , such as train diagrams, timetable/delay statistics, and speed/time diagrams [38, 39]. It also offers more capabilities for automatically resolving the conflicts based on train priority, routing options and delay probabilistic functions than typical timetable-based simulation software. A summary of features and other characteristics of each simulation package used in this study are presented in

Table 2.

Table 2 - Summary of rail simulation packages used in the project

Category	RTC	RailSys	OpenTrack
Version of Software	67 Z (2013)	7.9.14 (2013)	1.7.5 (2014)
Country of Origin	U.S.	Germany	Switzerland
Operation Principle	Non-timetable based	Timetable based	Timetable based
Databases (Rolling stock / signals)	U.S. Default	Mainly European system	Mainly European system
Special Features	• "Meet-pass N-train logic" (dispatch / conflict) • Train movement animation	• Timetable management features (conflicts) • Timetable optimization (UIC 406) • "Multi-window" analysis tools	• Automatic conflict resolve (priorities, routings, and delay functions) • Extensive simulation messaging and outputs
Example Users	Class 1 freight RRs in North America: (UPRR, BNSF, CSX, NS, KCS, CN, CP, Amtrak), U.S. railway consultants, urban rail transit agencies	Many European rail operators and consultants, international rail companies	Many European rail operators and consultants, international rail companies

1-6-2 Review of Hybrid Analytical-Simulation Tool (HOTS Model)

In addition to the simulation tools, the study took advantage of a new analytical model, called "Hybrid Optimization of Train Schedules" (HOTS), developed at Michigan Tech. HOTS is a rescheduling model that uses an initial timetable to develop a conflict-free and compressed timetable based on user-defined criteria [40]. The optimization algorithm in HOTS model was used in this research for different rescheduling scenarios to facilitate the procedure of the developing simulation results.

The HOTS modeling approach is called “hybrid”, as it works as an “add-on” to any one of the existing rail simulation tools (such as RTC, RailSys or OpenTrack), extending their capabilities to include the timetable compression technique or the ability to adjust the train schedule parameters. The primary contributions of the HOTS model can be summarized as:

- Simultaneously resolves conflicts and compresses the initial timetable
- Applicable on different infrastructure topologies (single-, double-, and multiple-track) and operational patterns (directional and non-directional)
- Incorporates various flexibility parameters for rescheduling (min/max. allowed dwell time, and early/late departure time deviation)
- Includes two patterns of rescheduling (“same-order” and “order-free”)

HOTS is formulated as a multi-objective linear programming model. It attempts to minimize the departure time of trains as well as the deviation between proposed dwell time and the respective minimum value for each train, based on user-defined flexibility parameters of train schedule. The optimization concept of HOTS model is derived from UIC’s timetable compression technique and the decision core attempts to simultaneously perform “Conflict Resolution” and “Timetable Compression”. Thus, the initial timetable is always under pressure from both sides of decision core to provide a conflict-free and compressed timetable as the outcome of rescheduling problem (Figure 6). More details about the HOTS model applications and relevant test scenarios solved by this model can be found in the paper, Pouryousef, et al 2015. [40]

Figure 6 - Main Decision Core of HOTS Model

TASK 2 DATA COLLECTION

The simulation and modeling tools used the collected datasets to evaluate the capacity and LOS parameters for the project's case studies. Amtrak and Michigan Department of Transportation (MDOT) provided data of Washington DC-Baltimore section of NEC corridor and Detroit-Jackson section of Detroit-Chicago accelerated passenger corridor [1] for analysis, respectively. The provided categorized data is as follows:

- **Infrastructure database**: the horizontal and vertical track alignments (grades and grade changes, switch locations, horizontal curves and speed limits, signal locations, track directions, track layouts in the sidings/yards, etc.)
- **Rolling stock database**: type, quantity and characteristics of trains (cars length, weight of train, engine details)
- **Signaling system**: The type of signaling systems (wayside and cab-signaling systems) including interlocking and block characteristics, signal aspects and associated speed limits, overlays through yards and sidings
- **Operations rules**: speed limits, headway, dwell time, initial train schedules (arrival and departure times), train priorities, maintenance slots (if planned).

Each dataset was provided in RTC format.

Table 3 compares primary operational and network characteristics of the two cases, followed by a more detailed description of each.

Table 3 - Comparison between case study parameters

Parameter	**NEC (Washington, DC - Baltimore, MD)**	**Michigan (Detroit - Jackson)**
Type of operations	Multiple-track, non-directional	Single-track, non-directional
Length of corridor	40.6 miles	78.7 miles
Length of double track	1.48 miles	Approx. 17 miles
Length of triple track	33.94 miles	NA
Length of quadruple track	5.18 miles	NA
# of yards/stations	9 (2 yards + 7 stations)	11 (2 yards + 6 stations + 3 sidings)
Turnout #s	# 32.5, # 15 (one crossover)	# 9, # 18, # 20, #30
Max vertical grade	2.12%	1.16%
Horizontal Curvature	0.01 - 7.27 degrees	1.00 – 4.00 degrees
Traction power	Electrified + Diesel-electric	Diesel-electric
Type of trains	Passenger (Acela + Commuter + Intercity)	Intercity Passenger + Freight
Trains priority	Acela/Commuter/Amtrak	Amtrak/Intermodal/Freight

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[1] Note: *The research uses the Baltimore-Washington, D.C. and Detroit-Jackson of corridors as two stand-alone segments of rail infrastructure and does not examine continuations of routes on either end of these two corridors. The objective of the research was not to evaluate or recommend any changes to current NEC and MI rail operations, but rather to take advantage of actual infrastructure and train operation data to understand the impact of different operation philosophies along single and multiple-track corridors in self-contained context. Since these two case studies did not consider the movement of trains beyond the study limits, none of the suggested modifications are implementable without further study that evaluates the impacts and challenges over the entire length of the corridors.*

# of daily trains	136 daily trains	50 (6 intercity passengers + 44 local and long distance freight)
Signaling System	Cab signaling + Wayside signals	Wayside signals
Max operation speed	120 mph	79 mph (part of the line)

2-1 NEC Case Study Characteristics

The segment of the Northeast Corridor (NEC) between Baltimore, MD and Washington, DC is one of the most congested and complicated corridors in the U.S. rail network in terms of:

- Number of trains per day
- Diversity of train types
- Operation of the only high speed train service in the U.S. (Acela Express)
- Complexity of signaling systems (both wayside and cab signaling systems)
- Number of tracks along the corridor (sections with triple and quadruple tracks)

With its complexity, NEC provides an excellent case to investigate the effects of directional/non-directional operation patterns on capacity utilization and LOS parameters in the U.S. rail environment.

2-1-1 Infrastructure

The case study's infrastructure contains 40.6 miles of triple-track, (approximately 5 miles of quadruple and approximately 1.5 miles of double-track) with several crossovers and intermediate stations/platforms along the corridor (Figure 7). Horizontal and vertical alignments from RTC database were used to develop both OpenTrack and RailSys input databases for the research.

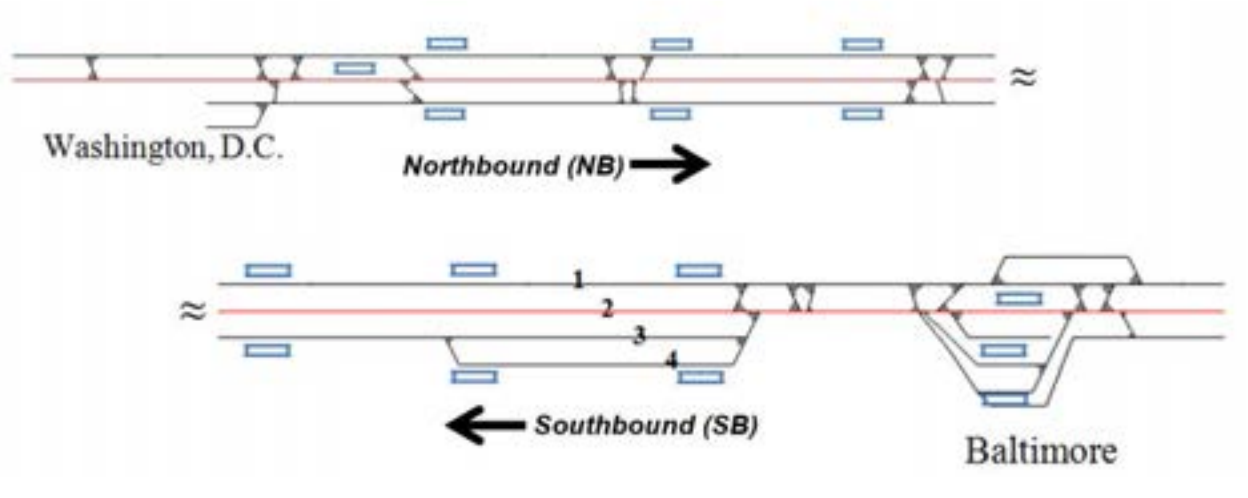

Figure 7 - Snapshot of the case study infrastructure between Washington DC- Baltimore, MD

As shown in Figure 7, most intermediate station platforms can only be accessed from specific tracks, with the exception of the Baltimore station. Platform arrangements in Washington, D.C. station were not considered in the analysis. The lack of access to platforms from certain tracks limits train operations, especially in Northbound direction (from Washington, D.C. to Baltimore), as trains with passenger boarding/disembarking activities must use Tracks #3 or #4. This also increases the need for the use of crossovers in the vicinity of stations to access those tracks.

In current operations, trains use 28 different routes in the corridor (total for both directions), 16 of which are used for northbound direction and 12 for the southbound operations. Nine routes (out of 28) do not use crossovers while the remaining 19 do. Figure 8 shows four example routes used by northbound (NB) and southbound (SB) trains.

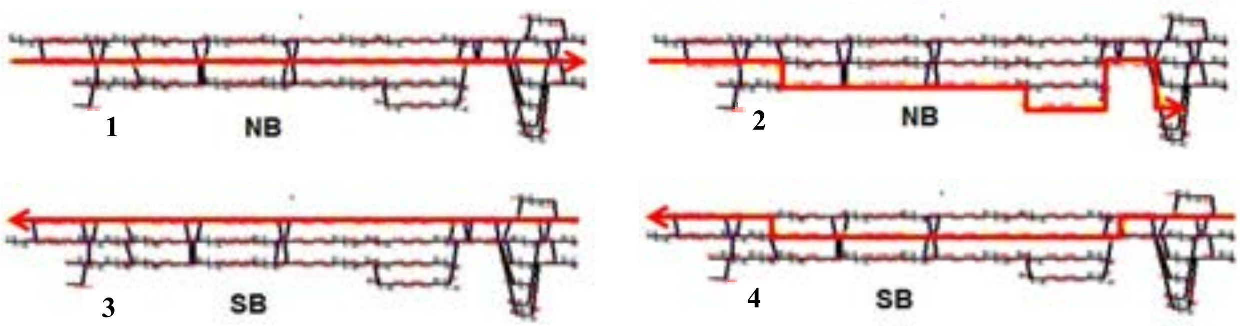

Figure 8 - Four examples of routes (1: directional NB, 2: non-directional NB, 3: directional SB, 4: non-directional SB)

2-1-2 Signaling Characteristics

The signaling system includes a wayside system under CTC control and a cab signaling system. These two systems were integrated and now work in unison to improve the capacity and safety levels of the corridor. All trains running through NEC are required to be equipped with working cab signals and in the case of failure of the cab signals, the dispatcher grants permission for movement in the absolute block between each interlocking, with a reduced, 79 mph speed limit.

2-1-3 Rolling Stock Characteristics

All types of passenger trains operating on the corridor have been included in the case study; Long-distance Passenger, Commuter, Regional Amtrak, and High Speed trains (Acela). There is no freight traffic on the segment under investigation. The NEC (including the Baltimore-Washington, DC section) is one of the few electrified corridors in the U.S. and some of the trains considered in this case study (including Acela trains) use overhead power supply system. The main characteristics of the rolling stock used in the case study are presented in Table 4.

Table 4- Main features of case study's trains

Train	Daily trains (pairs)	# of cars	Trailing weight (ton)	Trailing length (feet)
Acela	10	6	378	649
Long-distance Amtrak	10	9	450	816
Regional Amtrak	10	7	385	744
Commuter	10	5	175	483

2-1-4 Operation Rules

There are several operation rules for simulation, including the train priority, speed limits, stopping patterns, and preferred time and order of train departures. The priority by train type (from highest to lowest) is Acela, Commuter, Regional, and Long-distance trains. The predefined arrival/departure times and preferred priority of trains were replicated in the RailSys and OpenTrack simulation databases for all trains. The Acela train is capable of operating at speeds up to 137 mph, but the actual speed of Acela and passenger trains is limited to 120 mph (90 mph for commuter trains), due to track profile, overhead, and crossovers restrictions. The initial speed of all trains from Washington, DC toward Baltimore, MD (Northbound direction) was 30 mph when they reached the track segment starting the simulation process. For the southbound direction, the initial speed of trains had to be maintained at 30 mph for approximately 1.2 miles after entering the simulated segment, due to the speed limits at "Baltimore-Bridge". Trains had different intermediate stops, however, all trains stopped at Baltimore and Washington, D.C. Some Acela trains had no intermediate stops in the case study segment.

2-2 Michigan Accelerated Passenger Corridor

The Michigan passenger rail system consists of three corridors, including the Chicago-Detroit/Pontiac corridor, the Chicago-Grand Rapids corridor, and the Chicago-Battle Creek-Port Huron corridor. The Chicago-Detroit segment is one of the corridors in the U.S. to be considered for higher speed passenger operations. The research team focused on a 78.7-mile segment between Detroit-Jackson and created the RailSys and OpenTrack databases for this segment by replicating the RTC database provided by MDOT.

2-2-1 Infrastructure Characteristics

The Detroit-Jackson section contains 61.7 miles of single track and 17 miles of double track (Detroit-Dearborn, Wayne-YPSI), as depicted in Figure 9. There are several intermediate stations/ sidings along the corridor. Detroit (DET), Wayne (WAY), and Jackson (JACK) are the main yards/stations. The other stations are Dearborn (DEAR), Ypsilanti (YPSI), Ann Arbor (ANN), Chelsea (Chelsea) and Miller (MILL).

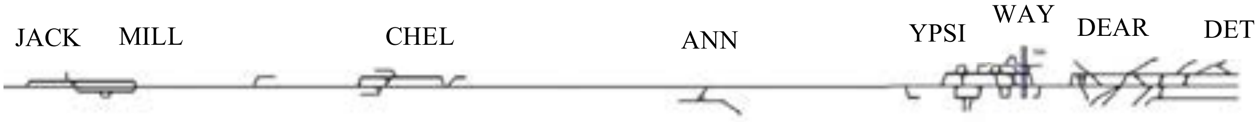

Figure 9- Snapshot of the case study infrastructure between Detroit-Jackson

2-2-2 Signaling Characteristics

The signaling system includes wayside signals under CTC control system. The current wayside signals are equipped with 3-aspect signaling system to manage the inbound-outbound traffic along the main line and at the stations. In the future along Kalamazoo-Chicago section, there is a plan to integrate the current signaling system with more advanced technology called Incremental Train Control System (ITCS), which has been in use by Amtrak since 2000.

2-2-3 Rolling Stock Characteristics

More than 50 daily passenger and freight trains are operated along this section of Detroit-Chicago corridor (the exact number of trains is varied in weekdays and weekends). Currently, there are no commuter trains running, but daily service between Detroit-Jackson and Detroit-Ann Arbor is planned by 2017. Several freight trains are operated by different class 1 railroads, including CN, NS, CP and CSX. Approximately 20 of these trains are local freight services that operate between Milwaukee junction and industrial tracks around Detroit yard and thus affect the Detroit-Jackson mainline operations at the entrance to Detroit yard. Similar train consist adjustments as in the NEC case study were made in the RailSys (OpenTrack) to provide accurate train performance. The main characteristics of rolling stock used in the case study are presented in Table 5.

Table 5- Main features of Detroit-Chicago trains (Wednesday operations)

Train	Daily trains (pairs)	# of cars	Trailing weight (ton)	Trailing length (feet)
Amtrak	6	4 - 6	248 - 373	340 - 510
Intermodal	4	75 - 90	1725 - 7200	4198 - 5000
Auto Train	10	75 - 100	2250 - 9750	7050 - 9000
Manifest	23	25 - 125	2250 - 13000	1400 - 9000
Unit	3	30 - 130	900 - 13000	1650 - 7078
Local	4	25 - 40	2250 - 3900	1150 - 1300

2-2-4 Operation Rules

Similar to the NEC, several operation rules including the train priority, speed limits, stopping patterns, and preferred time and order of train departures, were considered for Detroit-Jackson case study. Train priority (in descending order) was intercity passenger trains (Amtrak), Intermodal, Auto Train, Manifest, Unit and Local trains. The predefined arrival/departure times and preferred priority of trains were replicated in RailSys and OpenTrack simulation database based on requested schedule in RTC. The maximum speed of Amtrak trains was limited to max 79 mph along this section of the corridor and max speed for the freight trains was 70 mph. The software calculated the actual speed for all trains, based upon the track profile and speed restrictions. Passenger and freight trains had various intermediate stops and all passenger trains stopped at Detroit, Dearborn, Ann Arbor and Jackson stations.

TASK 3 DATABASE IMPLEMENTATION AND RESEARCH METHODOLOGY

This chapter explains the implementation of the database for given case studies. It also briefly explains the research methodology used in this project. As mentioned earlier, the study used three simulation packages, together with HOTS model. All tools used for research have specific capabilities that justify their use in the study, as summarized in Table 6**Error! Reference source not found.**.

Table 6 – Summary of specific features and capabilities of each simulation tool/model and justification of use

Tool	RTC	RailSys	OpenTrack	HOTS Model
Features and Capabilities	• Automatic train conflict resolution • Informative and customized train movement animation • Extensive U.S. signaling and rolling stock database	• Timetable management features • Timetable optimization (timetable compression technique) • Multi-window capabilities	• Automatic train conflict resolution • Extensive simulation messaging and outputs	• Customized rescheduling features • Optimization algorithm for improving train schedules
Justification	•The initial database of each case study was provided in RTC format •A benchmark for replicating the database in other simulation tools	• Heuristic timetable management capabilities • High level of credibility for results (industry-proven)		•Requires less expertise and knowledge for rescheduling than simulation tools •Quicker and more conveniently to apply different scenarios compared to only simulation •Customizable parameters

RTC was an essential tool as the data for the case studies was provided in RTC format. In addition, the animation features of RTC were very informative for analyzing the train movements and signaling aspects along the main lines. RailSys and OpenTrack's convenient rerouting and rescheduling features were used to automatically adjust the schedule and provide route alternatives. However, using these tools requires a certain level of expertise in simulation and software tools. The HOTS model offered an alternative to rescheduling, as it is equipped with several customizable parameters to adjust the train schedules based upon the user-defined preferences. Once initial simulation results are obtained, HOTS can be used to perform rescheduling analytically, without the need for high level of simulation expertise. The approaches used for the research included:

- Combined Simulation; RTC with Railsys/OpenTrack
- Combined Simulation + HOTS Model

3-1 Combined Simulation Approach

The combined simulation approach used the database and output from RTC as an input to RailSys/OpenTrack for rescheduling through available timetable management features. The adjusted schedules were evaluated in terms of capacity utilization and LOS parameters. Figure 10 details the process workflow.

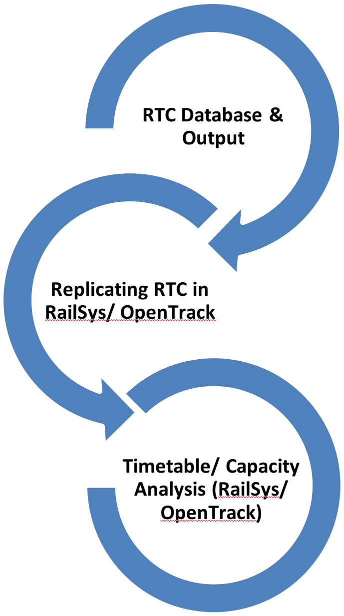

Figure 10 - Main steps of "Combined Simulation Approach"

3-2 Combined Simulation + HOTS Model Approach

The workflow process for the HOTS model approach (Figure 11) was similar to combined simulation, except for the last step, where HOTS model optimization features were applied in addition to the timetable management features by RailSys/OpenTrack. A bilateral relationship between HOTS model and simulation tools allows new train schedule to be developed by HOTS for validation and further analysis in the simulation tools.

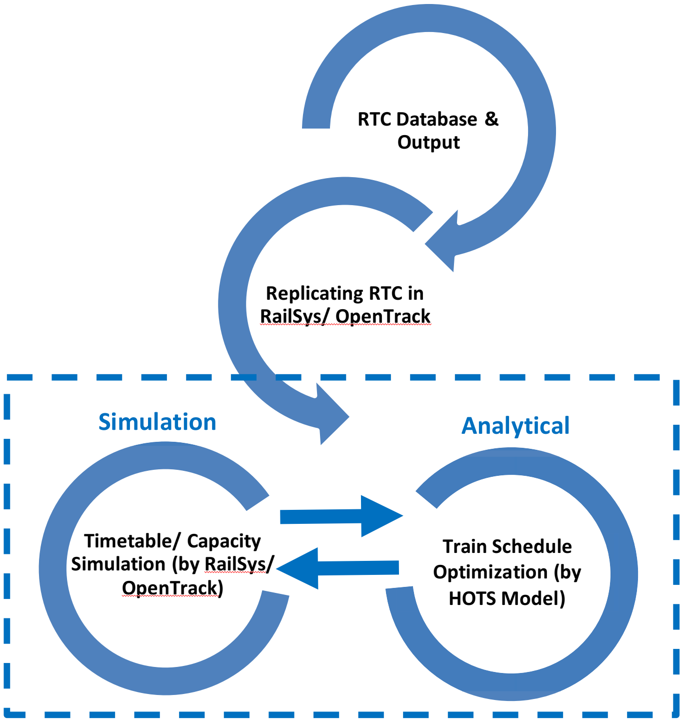

Figure 11 - Main steps of "Combined Simulation + HOTS Model Approach"

3-3 Case Study Scenarios

Three main scenarios developed for each case study are presented in Table 7.

Table 7 - Case Study Scenarios

Case Study	Scenario	Objective	Approach	Evaluation Parameters
NEC	**1- Base Model** (Initial schedule)	**A benchmark** for: • accuracy of replicated simulation • evaluating the LOS and capacity changes in scenarios 2 and 3	Combined Simulation	• Train speed • Train delay • Track occupancy level • Access to platforms at stations (sidings) • Train schedules before and after changes • Dwell time • Stop pattern
	2- "Heuristic Rescheduling/Rerouting" Scenario	To develop a fully directional operation pattern using rerouting/ rescheduling features of RailSys/OpenTrack **heuristically**	Combined Simulation	
	3- "Rescheduling/ rerouting based on HOTS" Scenario *(Including three sub-scenarios)*	To develop a fully directional operation pattern using **"HOTS model"** optimization instead of heuristics	Combined Simulation + HOTS model	
Michigan	**1- Base Model** (Initial schedule)	**A benchmark** for: • accuracy of replicated simulation • evaluating the LOS and capacity changes in scenarios 2 and 3	Combined Simulation	• Number of additional train services • Track occupancy level • Train schedules before and after changes • Dwell time • Stop pattern
	2- "Adding freight trains" Scenario	To add **"new freight trains"** to the initial schedule	Combined Simulation + HOTS model	
	3- "Adding commuter trains" Scenario *(Including two sub-scenarios)*	To add **"new commuter trains"** to the initial schedule	Combined Simulation + HOTS model	

Scenario 1 of each case study represents the current, "as-is", schedule and operation patterns serves as the benchmark for schedule changes in Scenarios 2 and 3. The objective of the NEC case study Scenarios 2 and 3 was to provide a fully directional pattern for existing trains. NEC Scenario 2 used a heuristic approach of rerouting/rescheduling techniques/rules similar to what a practical railway dispatcher may apply based on his/her level of expertise knowledge. NEC Scenario 3 used analytical HOTS model's capabilities of rerouting/rescheduling to provide a fully directional pattern of operations. Scenario 3 included three sub-scenarios that used different rescheduling rules (same-order vs. order-free).

The Michigan case study Scenarios 2 and 3 used HOTS model rescheduling capabilities combined with RailSys simulation features to add new services to the initial schedule without requiring infrastructure improvements. In Michigan case study, new freight (Scenario 2) and commuter (Scenario 3) trains were added with minimized schedule changes for the existing passenger/commuter trains. Chapter 4 provides a more detailed description of each scenario.

3-4 Data Management

The combined approach requires RTC databases to be converted to RailSys/OpenTrack (Table 8). The conversion of infrastructure and operating rules is straightforward and consists mainly of unit conversion (English to metric). However, converting train and signaling characteristics are more complicated and may require specific adjustments in individual parameters, as the train performance calculator (TPC) and signal system emulator of RailSys (and many other European-based simulation tools) are less sophisticated and are configured for U.S. operations. RTC's capabilities are customized for the U.S. rail environment.

Table 8 - Summary of database conversion from RTC to RailSys/OpenTrack

Category	**Conversion Criteria**	**Difficulty Level**	**Main Adjustments**
Operation rules	Match	Straightforward	Unit conversion
Trains	Maintain trains run times	Complicated	Train consist, Power, Max speed, Train resistance
Signaling	Maintain routes and run times	Complicated	Signal features, Interlocking, Blocks
Infrastructure	Match	Straightforward	Unit conversion

The main objective of the conversion was to maintain the same schedule and run time of trains, as well as to confirm that there were no deviations in train routings. Due to the different rail operations and network characteristics between North America and Europe, key simulation outcomes must be checked to ensure they match with each other. An iterative validation was used to compare the results of RTC and RailSys/OpenTrack outputs and determine if further adjustments were required to the parameters. Table 9 presents the outcome comparison between the replicated simulations in RailSys/OpenTrack and the original database in RTC. Since the Michigan segment was a part of a complete Chicago-Detroit corridor in RTC, the team manually calculated comparison parameters to confirm the quality of replication.

Table 9 - Comparison between initial timetable (RTC) and replicated timetable (RailSys and OpenTrack)

Evaluation Criteria	**Case Study**	**Initial Timetable**	**Replicated Timetable**	
		RTC	**RailSys**	**OpenTrack**
Version of Software		67 Z (2013)	7.9.14 (2013)	1.7.5 (2014)
No. of Daily Trains Successfully Simulated	**NEC**	136	136	136
	Michigan	50	50	-
Total Delay of All Trains	**NEC**	56.6 min	103.5 min	83.4 min
	Michigan	76.7 min	107.5 min	-
Avg. Delay per Train	**NEC**	25 sec	45 sec	37 sec
	Michigan	112 sec	129 sec	-
Similarity with Initial Timetable		N/A	Same stop pattern and same order of trains, minor deviations of arrival/departure times	

As shown in Table 9, the absolute values of RailSys/OpenTrack simulations with replicated databases are different from the RTC results. The value of average delay per train in RailSys/OpenTrack is

45 and 37 seconds, (respectively for RailSys and OpenTrack) versus 25 seconds[2] in RTC. The absolute difference between simulation runs is unavoidable and their effect on the overall simulation results are minor. The replicated simulation results of RailSys in Michigan case study were closer to the original RTC results (129 sec vs. 112 sec).

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[2] Average per train delays shorter than one minute, particularly for passenger services, are considered negligible in real practices.

TASK 4 EVALUATING THE ALTERNATIVE SCENARIOS

This chapter explains the main steps, applied tools/techniques used in each scenario, and demonstrates the simulation/HOTS analysis results (presented in Excel).

4-1 Review of NEC Scenarios and Results

As pointed out in Chapter 1, most of the double tracks in the U.S., including the NEC corridor, are operated in a non-directional pattern, while European rail systems commonly use a directional operation pattern. This study considered the following parameters for evaluating the effects of directional/non-directional operations on capacity and LOS:

- Train speed
- Train delay
- Track occupancy level
- Access to platforms at stations (sidings)
- Overtaking alternatives
- Train schedules before and after changes (e.g. status of directional/non-directional of trains, stop pattern, preferred departure time, etc.)

The current non-directional NEC (Washington, DC – Baltimore, MD) segment schedules are the benchmark for the comparison of capacity, LOS, and operational patterns in Scenarios 2 and 3. The NEC corridor is currently operated under non-directional pattern, as to:

- **Provide access to the station platforms:** Some tracks (particularly track #2) cannot provide access to the platforms for trains stopping at a particular station (Figure 7)
- **Allow faster trains to overtake slower trains:** Acela trains running up to 120 mph along the line share the line with slower commuter trains that stop more frequently at stations

Under NEC Scenario 2 and 3, the non-directional operation pattern was converted to a fully directional pattern. After conversion, Scenario 2 was deemed more efficient and selected for the analysis of the impacts of directional/non-directional conversion on the capacity utilization and LOS parameters.

4-1-1 Scenario 1: Base Model (Initial Schedule)

4-1-1-1 Schedule Replication

The RTC database provided by Amtrak was used to build the base model ("Initial Schedule") and to create databases in RailSys and OpenTrack. Figure 12 shows the current schedule of Washington, DC-Baltimore, MD section of NEC corridor, in RTC format, over a 24-hour time horizon. For better visibility, two hours of the schedule were enlarged to show train schedule details (Figure 12-Bottom).

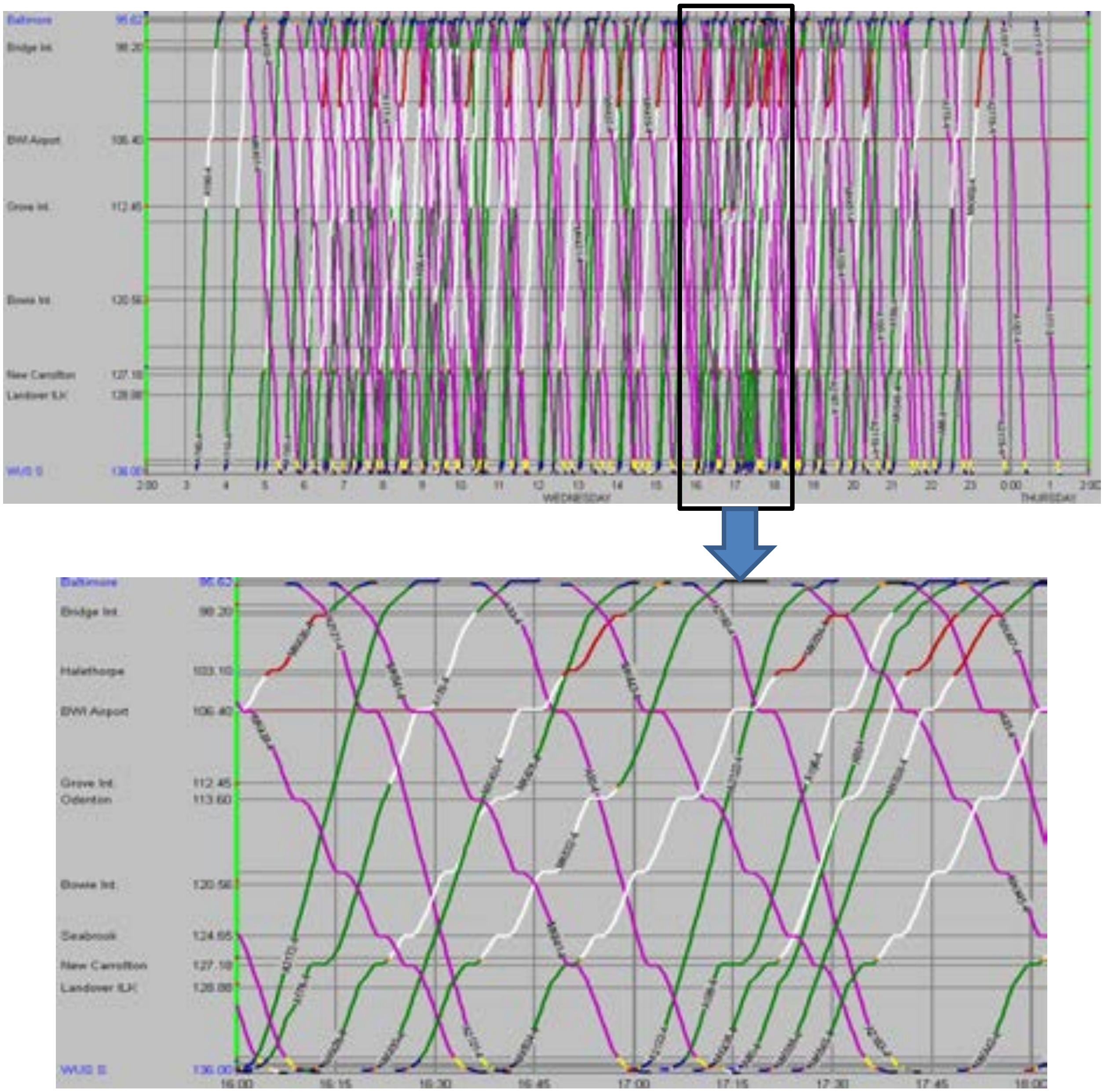

Figure 12 - (Top) Initial Timetable, Washington, DC-Baltimore daily schedule (RTC format); (Bottom) magnified 2-hour of daily schedule
(Note: different colors represent different tracks of the corridor)

Figure 13 shows the same RTC schedule replicated in RailSys and OpenTrack. The train schedules shown in RailSys and OpenTrack maintain the same stop pattern, order of trains, and similar arrival/departure times to the initial RTC schedule. Minor deviations ranging from several seconds to approximately three minutes in arrival/departure times are evident when comparing RTC and RailSys/OpenTrack results. The simulated train run time deviations along the corridor are attributed to differences in rolling stock and signaling in RailSys/OpenTrack (such as tractive effort of engines, acceleration, deceleration, braking diagram, etc.).

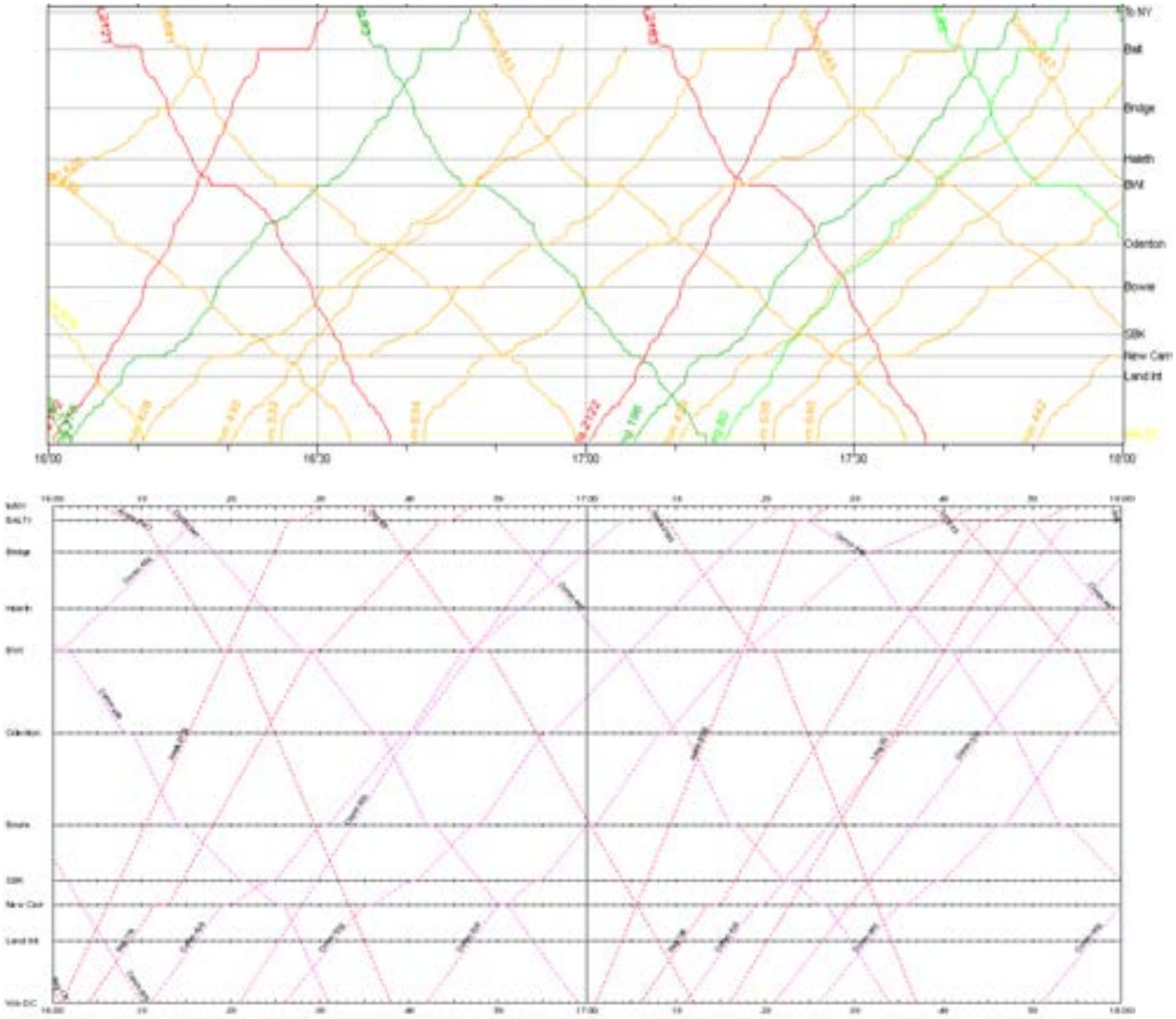

Figure 13 - The same RTC train schedule successfully replicated in RailSys (Top), and OpenTrack (Bottom)
(Note: in RailSys and OpenTrack, different colors represent different type of trains)

4-1-1-2 Review of Directional/Non-directional Train Status

RTC's animation feature was used to analyze the directional/non-directional status of trains in initial schedule (Figure 14). Almost 70% of the Acela trains operate in a directional pattern while the other trains are more evenly divided between directional/non-directional operations. Overall, southbound trains (Baltimore to Washington DC) use more directional patterns than northbound trains (Washington DC to Baltimore); mainly due to the lack of platform access from Track #2 at most intermediate stations.

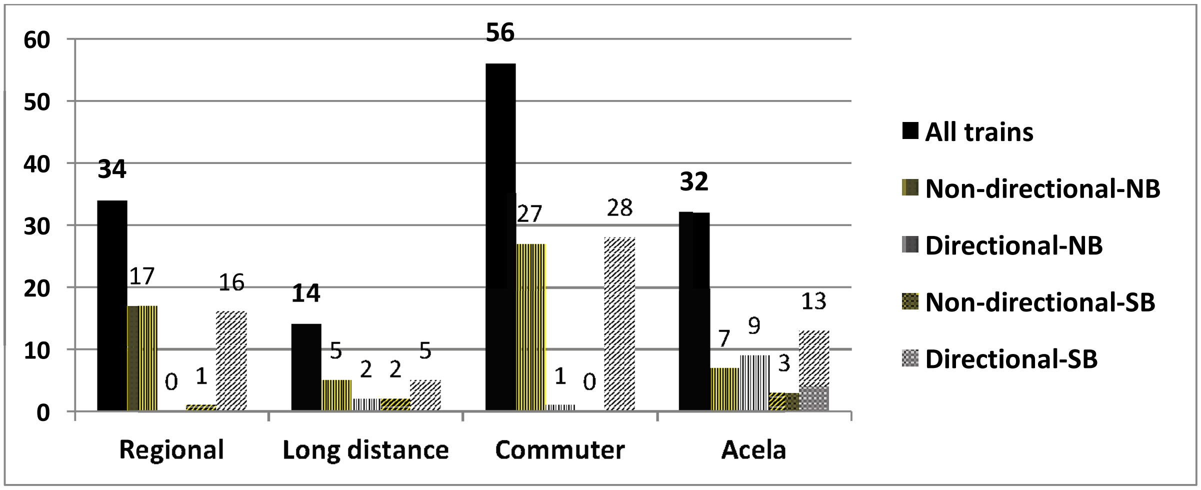

Figure 14 - Breakdown of directional/non-directional operations by train type and direction

RailSys was used to obtain train running time that includes train acceleration/deceleration and excludes dwell/wait times at stations. These run times were used to calculate average speed for each train type (Figure 15). The overall average speed of all NB direction trains (more non-directional trains) was 67.9 mph as compared to 72.8 mph for SB direction. The vertical profile of tracks derived from the original simulation database shows that ascending grades were approximately equal in both NB and SB directions and as such should not have a significant effect on the average speeds. There was a significant speed gap between directional and non-directional operational patterns for Acela (23.5 mph) and Commuter (15.2 mph) trains in the NB direction. Based on the routing analysis, it was concluded that the main reason for the large gap in operational speeds was the use of crossovers by the non-directional trains (particularly Acela).

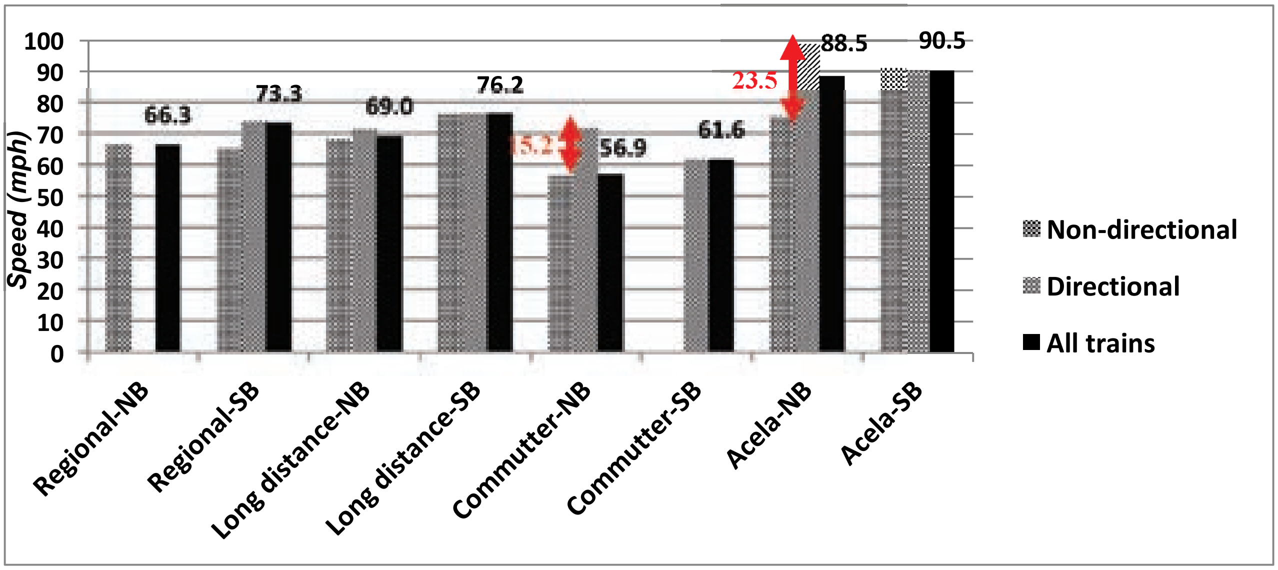

Figure 15 - Average speed of NB/SB trains with directional/non-directional operational pattern

According to the simulation results (Figure 16), NB trains have higher total delays than SB trains, however, it cannot be concluded that trains with non-directional pattern are more likely to have higher delays, as the concept of delay is more related to the risk of schedule disturbance and corridor congestion level than the physical conditions of infrastructure, or routing decisions.

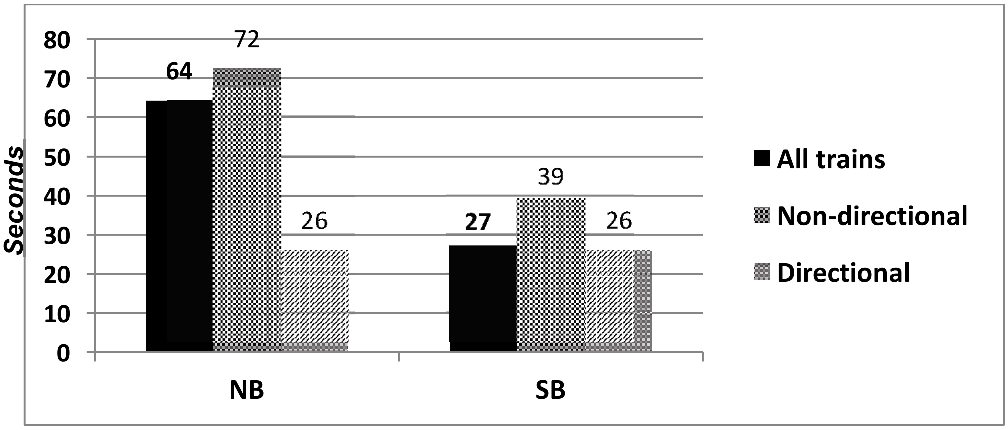

Figure 16 - Delay analysis for NB/SB trains (Average delay per train)

The above parameter values were further compared with those obtained in Scenarios 2 and 3, after the existing operation pattern was converted from non-directional to a fully directional operation pattern.

4-1-2 Scenario 2: Heuristic Rerouting/Rescheduling Method

Scenario 2 used a heuristic rerouting/rescheduling method through RailSys' timetable management features to convert the current non-directional operation pattern into a fully directional pattern. User expertise in simulation and/or timetable management tools was used to develop several heuristic rules and algorithms that mimicked a timetable development tool. The heuristic rules for converting a non-directional train schedules to a fully directional pattern included:

- Initial schedules of directional trains remain unchanged.
- Stop pattern and minimum dwell time of all trains are unchanged even if schedule or routing changes.
- Access to a side/island platform at designated stop locations along tracks #1 or #2 is available (this would require construction of new platforms).
- There are maximum departure time deviations (±X minutes) assumed for each train type. New schedules cannot exceed the train's maximum deviation as compared to the initial schedule. (Acela ± 15, Commuter ±40, Long Distance/Regional ±60.)

After heuristic rerouting/rescheduling, all trains move in directional pattern with northbound (NB) trains using Track #2 and southbound (SB) trains using Track #1. Since trains no longer used Tracks #3 or #4, these tracks would be available for new services (Track #4 only exists for a portion of corridor). Highlighted in Figure 17 is a two-hour period from the Scenario 2's stringline. In this example, several trains are rescheduled, rerouted or simultaneously rerouted/rescheduled to provide a fully directional operation pattern with no schedule conflicts.

As an example, the route of Acela train #2122 is demonstrated at the left side of Figure 17 to demonstrate the route conversion during the heuristic approach with the NB trains using Track#2 highlighted. After rerouting, all NB trains in this corridor segment, including #2122, are using Track #2 and thus have highlighted stringlines as presented in Figure 17-b. As result of this scenario, overtaking alternatives along the main line are no longer needed (an example is highlighted with a blue box in Figure 17-a).

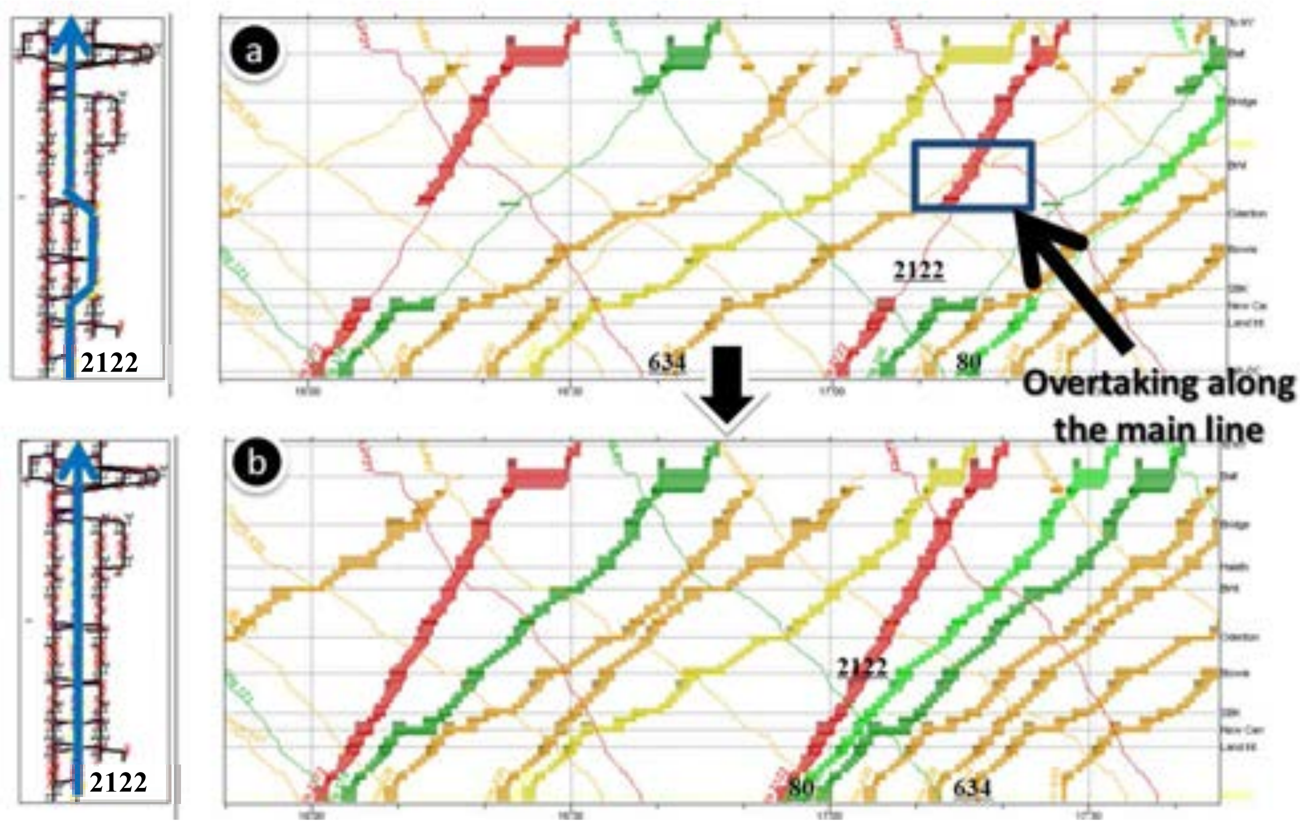

Figure 17 - (a) Initial schedule snapshot; (b) Scenario 2 schedule after heuristic rerouting/rescheduling method providing directional operations. *(Note: Different colors represent different train types. Highlighted stringlines show the NB trains using Track #2)*

The new schedules had an average departure time difference of eight minutes with a standard deviation of seven minutes. **Error! Reference source not found.** shows the schedule changes of trains highlighted in Figure 17.

Table 10 - Changes on selected trains highlighted resulting from running Scenario 2

Train #	Train Type	Departure Deviation	Rerouted (Y/N)	Rescheduled (Y/N)
80	Amtrak	19 min. earlier	N	Y
2122	Acela	5 min. earlier	Y	Y
634	Commuter	35 min. later	Y	Y

4-1-3 Scenario 3: Rerouting/Rescheduling based on HOTS Model

Although the heuristic method (Scenario 2) could provide a fully directional pattern for the corridor, it required a time-consuming database conversion and a certain level of user expertise and judgment to provide a feasible solution. Scenario 3's objective was the same as Scenario 2, but HOTS model replaced the heuristic rerouting/rescheduling.

The analysis was based on the base model (initial schedule) and defined flexibility parameters of HOTS model. Scenario 3 used the two rescheduling approaches available in HOTS model:

- **“Same-order” approach** maintains the initial departure order of the trains during rescheduling
- **“Order-free” approach** allows the departure order of the trains to change based on the maximum flexibility parameter (FDB parameter) to depart a train earlier than the initial departure time.

Three sub-scenarios were generated to demonstrate both approaches. Table 11 presents the sub-scenarios, flexibility parameters and allowed changes to trains that were already directional.

Table 11 - Sub-scenarios of using HOTS model to provide fully directional pattern over the initial schedule

Sub-Scenario	Rescheduling approach	Flexibility parameters	Existing directional trains
3-1- “Order-Free1”	Order-free	Fixed for each train type	---------------
3-2- “Order-Free2”	Order-free	Depends on the directional status of trains	Maintained, minor deviation allowed [1]
3-3- “Same-Order”	Same-order	Depends on the directional status of trains	Maintained, minor deviation allowed [1]

[1]: *The schedule of all directional trains and all Acela trains are maintained, but they are allowed to be dispatched later to resolve a conflict between train schedules, if needed.*

Both Sub-scenarios 3-1 and 3-2 used the “order-free approach. Sub-scenario 3-1 used the same rescheduling flexibility parameters for each train type. Sub-scenario 3-2 maintained the initial schedules of all existing directional trains and Acela trains, unless there was a rerouting/rescheduling conflict during the adjustments made for non-directional trains. These conflict situations could force a later departure, up to the maximum deviation assigned. Sub-scenario 3-3 used the same input database as Sub-scenario 3-2, but under the same-order rescheduling approach. In this study, HOTS model was run only once in each Sub-scenario. It should be noted that performing several iterations in HOTS model might provide more robust schedules and improve the results.

The primary flexibility parameters defined for Sub-scenario 3-1 and Sub-scenarios 3-2 and 3-3 are presented in Table 12 and Table 13 respectively.

Table 12 - Primary flexibility parameters of HOTS model defined in Sub-Scenario 3-1

Parameter	Acela	Commuter	Long-distance	Regional
Min. requested dwell time (min)[1]	1	1	1	1
Max. allowed dwell time (min)[2]	2	10	15	15
FDB[3] (min) [4]	20	60	120	120
FDA[5] (min)	20	60	60	60
Headway (min)	2	3	3	3
Priority of train	4	2	1	1

1: *Minimum dwell time for planned stop points, otherwise zero*
2*: Varied based on train type and configuration*
3*: Maximum early departure deviation (FDB)*
4*: FDB was assumed as zero for the origin stations (i.e. initial schedule maintained)*
5*: Maximum late departure deviation (FDA)*

Table 13 - Primary flexibility parameters of HOTS model defined in Sub-Scenario 3-2 and 3-3

Parameter	Acela	Commuter	Long-distance	Regional
Min. requested dwell time (min)[1]	1	1	1	1
Max. allowed dwell time (min)[2]	2	10	10	10
FDB[3] (min) [4]	0	30 [5]	30 [5]	30 [5]
FDA[6] (min)	20	60	60	60
Headway (min)	2	3	3	3
Priority of train	4	2	1	1

1: *Minimum dwell time for planned stop points, otherwise zero*
2*: Varied based on train type and configuration*
3*: Maximum early departure deviation (FDB)*
4*: FDB was assumed as zero for the origin stations (i.e. initial schedule maintained)*
5*: Maximum late departure deviation (FDA)*

Headway, priority and the minimum requested dwell times remained the same as in the initial schedule (Scenario 1), but the maximum allowed dwell time had higher values to facilitate a feasible solution by HOTS model. The maximum early and late departure deviation (FDB and FDA) provide the flexibility for rescheduling. The FDB flexibility parameter differed based on the directional status of the trains, but all sub-scenarios used the same defined FDA, headway, and priority parameters.

Figure 18 compares a two-hour period of "Sub-scenario 3-1" (Order-Free1) with the initial schedule (Scenario 1). As it was explained in Figure 17, all highlighted stringlines (train-paths) show whether NB trains use Track#2 or not. Several trains were either rescheduled, rerouted or simultaneously rerouted/rescheduled to provide fully directional operation pattern. For instance, a higher early departure deviation (FDB) allowed the regional train #538 to be rescheduled to depart before the Acela train #2122 since the train order change was also allowed in this scenario. Similar to Scenario 2 (heuristic approach) trains #2122 and #634 were simultaneously rerouted and rescheduled, but the schedule deviation proposed by HOTS model differed from those obtained in NEC Scenario 2. As highlighted in Figure 18, overtaking takes place within the station location rather than along the main line tracks (initial schedule). It should be noted that the suggested overtaking requires track siding/crossover rearrangements at selected stations.

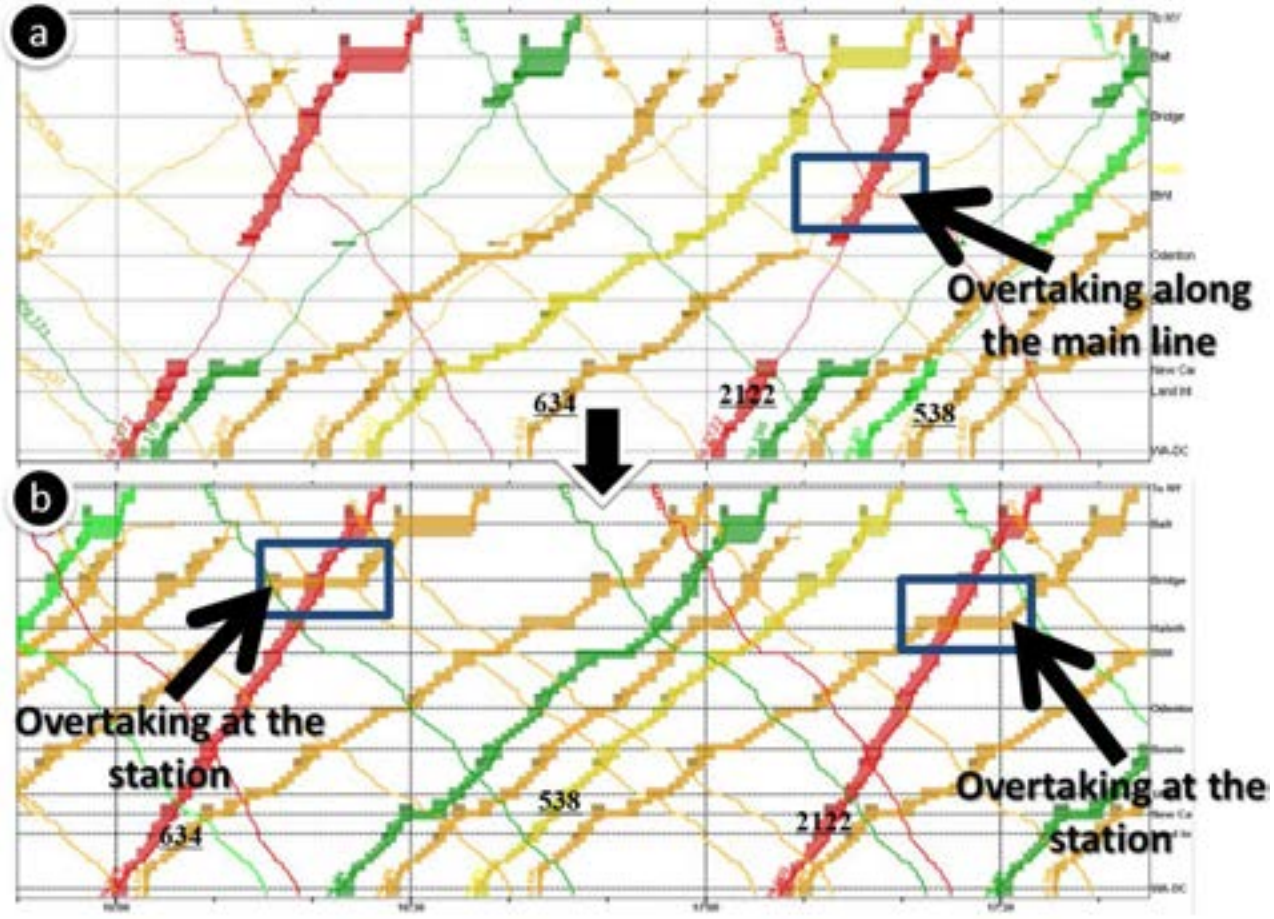

Figure 18 - (a) Initial schedule snapshot; (b) Scenario 3-1 (Order-Free1, fully directional) of HOTS
(Note: Different colors represent different train types. Highlighted stringlines show NB trains using Track #2)

Figure 19 shows the same time period as Sub-scenario 3-2, as illustrated in Sub-scenario 3-1. Sub-scenario 3-2 used different flexibility parameters based upon the directional status of trains. The figure shows that several trains were rescheduled/rerouted to provide a fully directional pattern. The changes in train order are highlighted in Figure 19. Overall, after fully directional conversion the schedule deviation was shorter than in the previous scenario However, some overtaking was still observed within the station locations, similar to the Scenario 3-1.

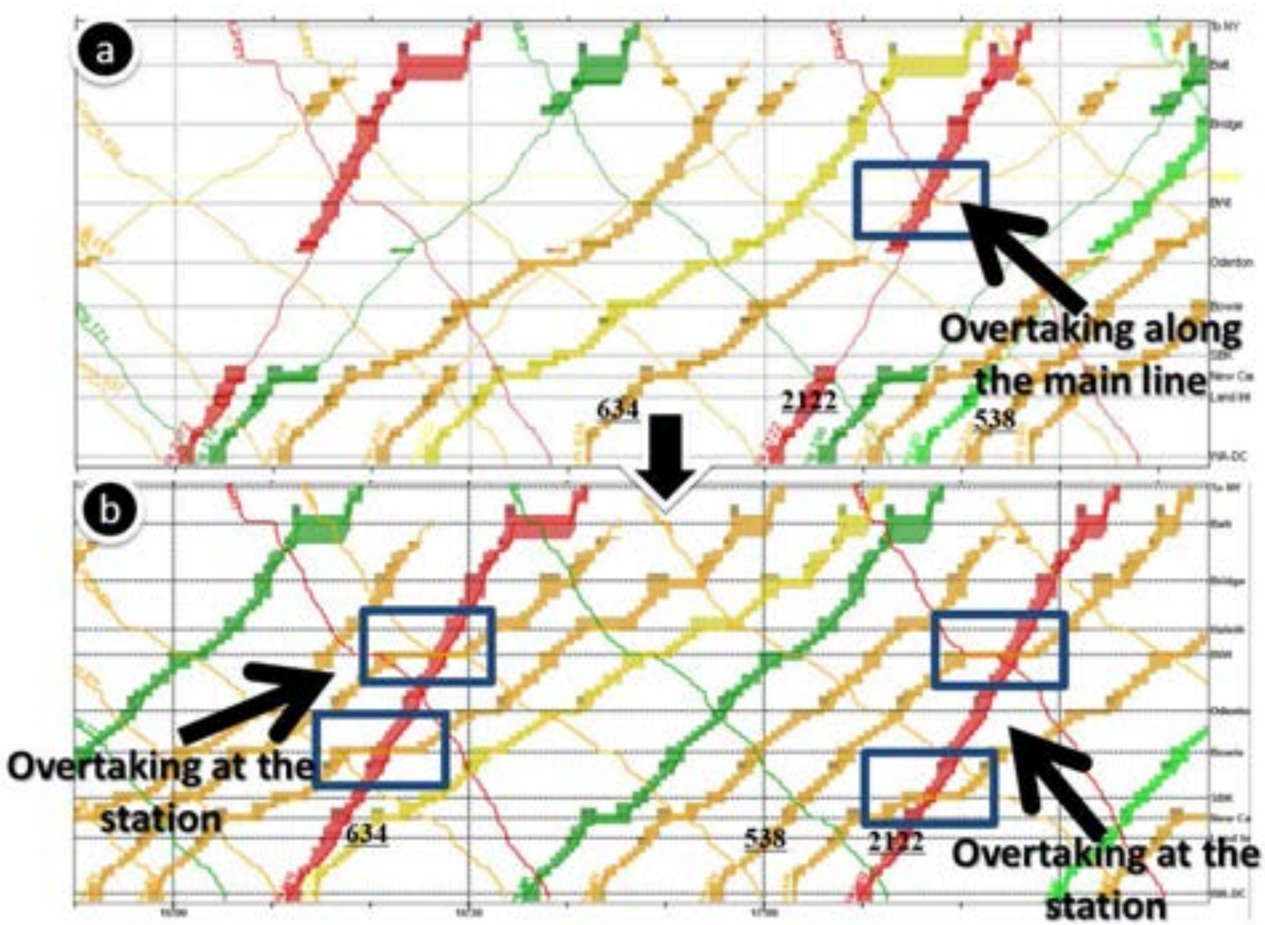

Figure 19 - (a) Snapshot of the initial schedule, and (b) Scenario 3-2 (Order-Free2) of HOTS model to provide fully directional operation pattern, while changing the train order was permitted (*Note: Different colors represent different train types. Highlighted stringlines show NB trains using Track #2)*

Using the same input database as Sub-scenario 3-2, HOTS created rerouting/rescheduling for Sub-scenario 3-3 using the Same-order approach (Figure 20). Although these two sub-scenarios had the same input database and similar flexibility parameters, less overtaking was observed in Sub-scenario 3-3 (Same-order) than the Sub-scenario 3-2 (Order-free). The average schedule deviation of same-order approach was slightly lower than in order-free approach.

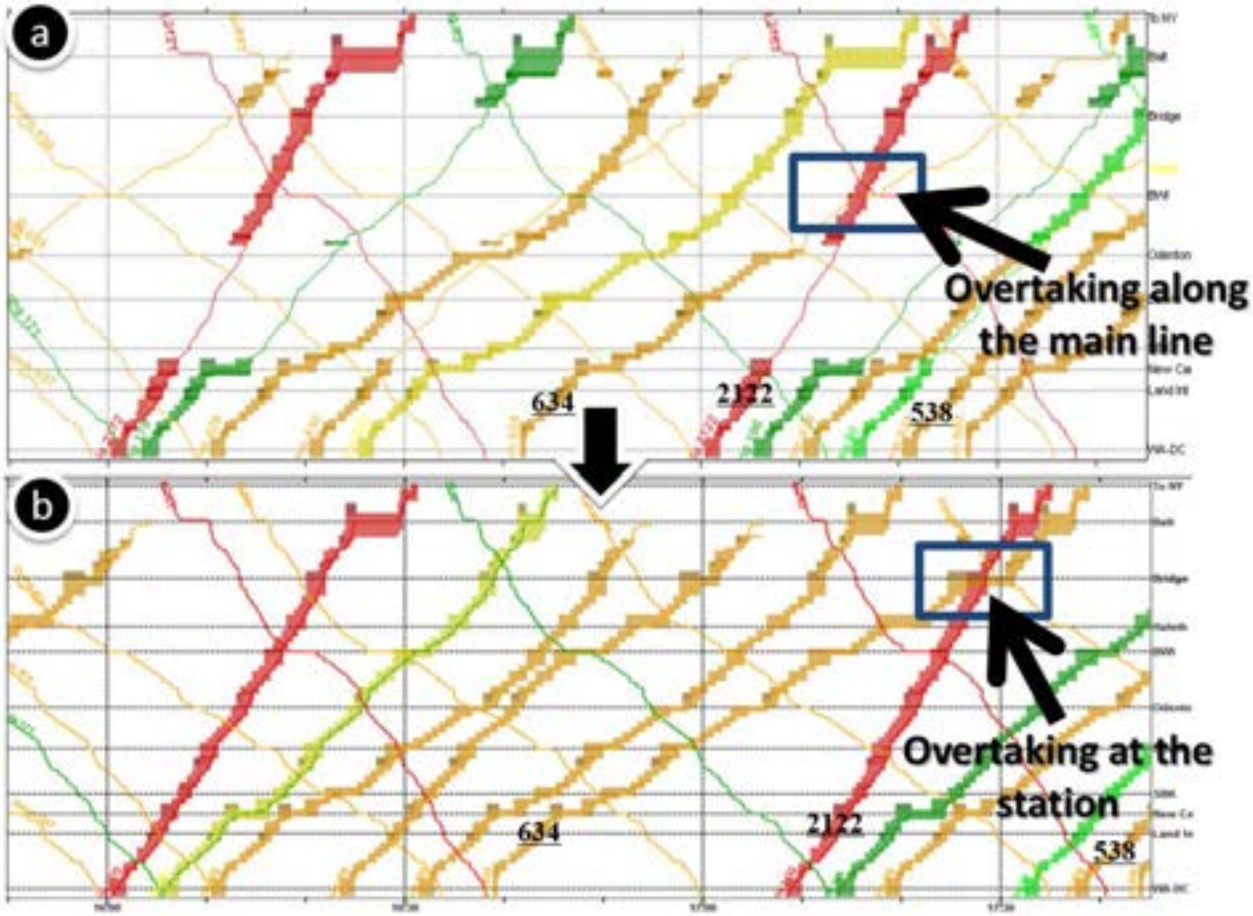

Figure 20 - (a) Initial schedule snapshot; (b) Scenario 3-3 (Same-Order) of HOTS model to provide fully directional operation pattern while maintaining the initial order of trains (*Note: Different colors represent different train types. Highlighted stringlines show NB trains using Track #2)*

4-1-4 Comparison between the Scenarios

Both Scenario 2 and 3 (including all sub-scenarios) successfully provided a fully directional operation pattern for the case study. Table 14 uses data extracted from RailSys and OpenTrack simulation reports to compare the results against the benchmark (Initial scenario).

Table 14 - Summary of the NEC multiple track scenarios in terms of directional and non-directional status

Parameter	Scenario 1 (Initial Schedule)	Scenario 2 (Heuristic)	Scenario 3 (HOTS model)		
			Sub- scenario 3-1 (Order-Free1)	Sub- scenario 3-2 (Order-Free2)	Sub- scenario 3-3 (Same-Order)
Operation pattern	Non-directional	Directional	Directional	Directional	Directional
# of tracks used	4	2	2	2	2
Overtaking (# of overtaking events)	At the main line (17)	No overtaking	At the stations (20)	At the stations (16)	At the stations (8)
Station/platform rearrangement requirements	-------------	Additional platform	- Additional platform Crossover modifications at the stations		
# of train stops	402	402	480	482	471
Max. observed dwell time (in Min)	3	2	11	10	10
Total dwell time (in Min)	557	473	603	581	538
Avg. deviation from initial schedule (in Min)	-------------	4.3	63.4	11.9	5.4
Standard deviation of schedule changes (in Min)	-------------	1.2	1.6	1.5	1.3
Max. deviation of schedule changes (in Min)	-------------	75	120	30	30

As presented in Table 14, Scenario 2 (heuristic) does not require any overtaking to provide fully directional operations, but it requires additional platform(s) (either island or side-platform) in certain stations to provide passenger access for the trains on Track #2. Other scenarios (3-1, 3-2, and 3-3) require additional platforms and a rearrangement of crossovers to facilitate the overtaking at certain stations. While the procedure of running the sub-scenarios under Scenario 3 with HOTS model was faster and more convenient from research perspective, the Heuristic model (Scenario 2) performed slightly better in terms of evaluated parameters.[3] Scenario 2 maintains the same number of stops as the initial schedule, but the maximum dwell time and total dwell time are shorter than in other scenarios. It also provides lower average schedule deviation, although the maximum schedule deviation is higher. Due to its better overall performance, Scenario 2 was used for non-directional/directional comparison.

4-1-5 Evaluating Directional vs. Non-Directional Patterns on Capacity and LOS Parameters

A detailed analysis was conducted between the Scenario 1 (Initial schedule) of non-directional operations and the Scenario 2 (heuristic) of fully directional operations to analyze the effects of rerouting/ rescheduling practices on the capacity and LOS parameters. The parameters analyzed included the total number of trains rerouted / rescheduled, and changes in train speeds and delays, track occupancy levels and capacity utilization (number of new daily trains added to the existing services). Data for analysis was extracted from RailSys simulation reports.

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[3] It should be emphasized that in this study HOTS model was run only once for each sub-scenario. Additional iterations of HOTS model might have improved the final results.

4-1-5-1 Number of Rescheduled/Rerouted Trains

The number of trains rerouted and/or rescheduled in the Heuristic Scenario (NEC Scenario 2) to achieve directional operations was evaluated, as keeping the number of operational changes to a minimum would facilitate the implementation. Figure 21 shows the number of trains rerouted, rescheduled, or rerouted and rescheduled under Scenario 2. Forty-six percent (46%) of all trains (NB and SB combined) maintained their initial routing and schedules, most of them were in SB direction. Twenty-seven percent (27%) of trains were rerouted, 6% rescheduled, and 21% (mainly NB trains) were simultaneously rerouted and/or rescheduled.

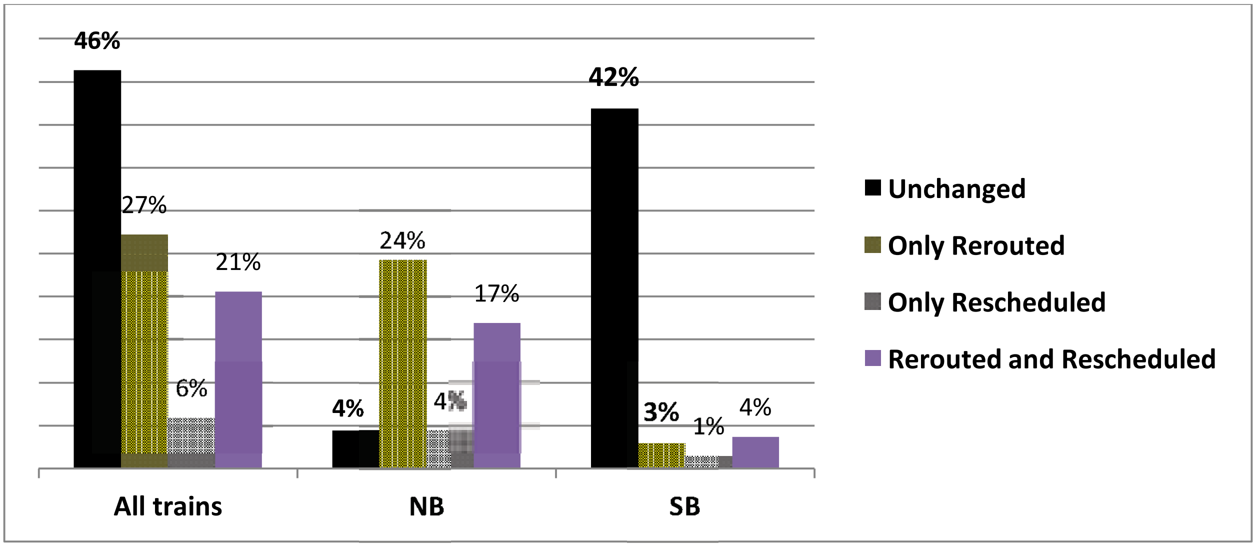

Figure 21 - Summary of rerouting and rescheduling changes under Scenario 2 (Heuristic method)

4-1-5-2 Effects of Rerouting/Rescheduling on Corridor Performance

The effects of rerouting/rescheduling on train performance were calculated and are shown in Table 15. The performance was divided to two main categories for analysis: **"Speed/Delay ",** and **"Track Occupancy level".** The green highlighted cells represent the scenario with better performance for those specific criteria.

Table 15 - Effects of Different Scenarios on Key Parameters

Evaluation Criteria			**Scenario 1 - Initial Schedule**	**Scenario 2- Fully Directional**
Speed/Delay	**Total delay of all Trains**		103.5 min	117.4 min
	Avg. delay per train		45.6 sec	51.8 sec
	Longest delay of a train		180 sec	161 sec
	Avg. speed of all trains		70.4 mph	71.9 mph
Track Occupancy Level	**Avg. track occupancy per day (%)**	**Track #1**	10.5%	10.8%
		Track #2	6.6%	11.6%
		Track #3	5.7%	0.0%
		Track #4	7.0%	0.0%
	Max. track occupancy per hour (%)	**Track #1**	50.7%	50.7%
		Track #2	36.9%	45.5%
		Track #3	34.4%	0.0%
		Track #4	19.2%	0.0%

Speed/Delay Analysis

As shown in Table 15, the **"Average speed of all trains"** was slightly higher in Scenario 2 than the initial schedule due to eliminating the use of crossovers. **"Total delay of all trains"** increased in Scenario 2 (directional approach) as more trains used Track #1 and Track #2, increasing the risk of traffic saturation (congestion) on those tracks. However, there was no significant difference in **"Average delay per train"** between the scenarios and in fact, the **"Longest train delay"** decreased in Scenario 2 (directional approach) due to the train rescheduling. The results suggest that moving from non-directional to directional operations has potential to increase speeds, but it also makes the given corridor more susceptible for train delays. Such trade-off between delay and speed parameters can be evaluated by using weighted value coefficients to determine the importance of each parameter against another.

Track Occupancy Level

Track occupancy level comparisons reveal that the **"Average track occupancy per day"** of Tracks #1 and #2 (the percentage of a given track occupied within 24-hour period) increased only slightly in directional approach (Scenario 2). The **"Maximum track occupancy per hour" (**the highest hourly percentage of a given track occupied by the trains) was maintained for Track #1, while it increased for Track #2 (45.5% vs. 36.9%), mainly due to increased number of trains using Track #2 under a directional operation pattern. Since the two remaining main tracks (#3 and #4) have no traffic under the directional approach, occupancy percentage dropped to zero, making them available for new traffic.

Additional Capacity

There is no clear methodology to quantify how much additional capacity can be provided through fully directional operation scenarios, as practical capacity depends on train types, preferred schedules and dispatching patterns of new services. However, it is evident that the directional approach has opened up capacity on Tracks #3 and #4, while only slightly increasing the occupancy levels of Tracks #1 and #2. For example, Track #3 used to have average daily utilization of 5.7% and maximum hourly utilization of 34.4%, but after all traffic was rerouted, its capacity utilization was zero.

Figure 22 presents an example of adding freight trains (shown in blue color) to Track #3 for both NB and SB directions. Overall, 22 new freight services were added to the corridor without disturbing existing passenger and commuter services. As highlighted in the figure below, the existing trains, such as Acela train #2122 and Amtrak train #80 maintained the same schedule and routing after adding new freight services (F13, F14 and F15). The new freight trains were initially planned to be equally dispatched in both directions in two-hour intervals from 3:00 until 23:00. Since these trains should partially share Track #2 with existing trains entering the Baltimore and Washington stations, the requested departure time of freight trains was manually modified in RailSys to avoid conflicts with any existing train schedules. In addition, two freight trains should partially use part of Track #1 (between Washington, DC and SBK) and Track #4 to avoid any conflict with existing trains during the morning and evening peak hours (approx. 8:00 am and 19:30 pm). Eventually, 17 out of 22 new freight services were dispatched with changes of 2 - 26 minutes from their requested schedules. The average schedule deviation and standard deviation were 6.9 minutes and 6.3, respectively.

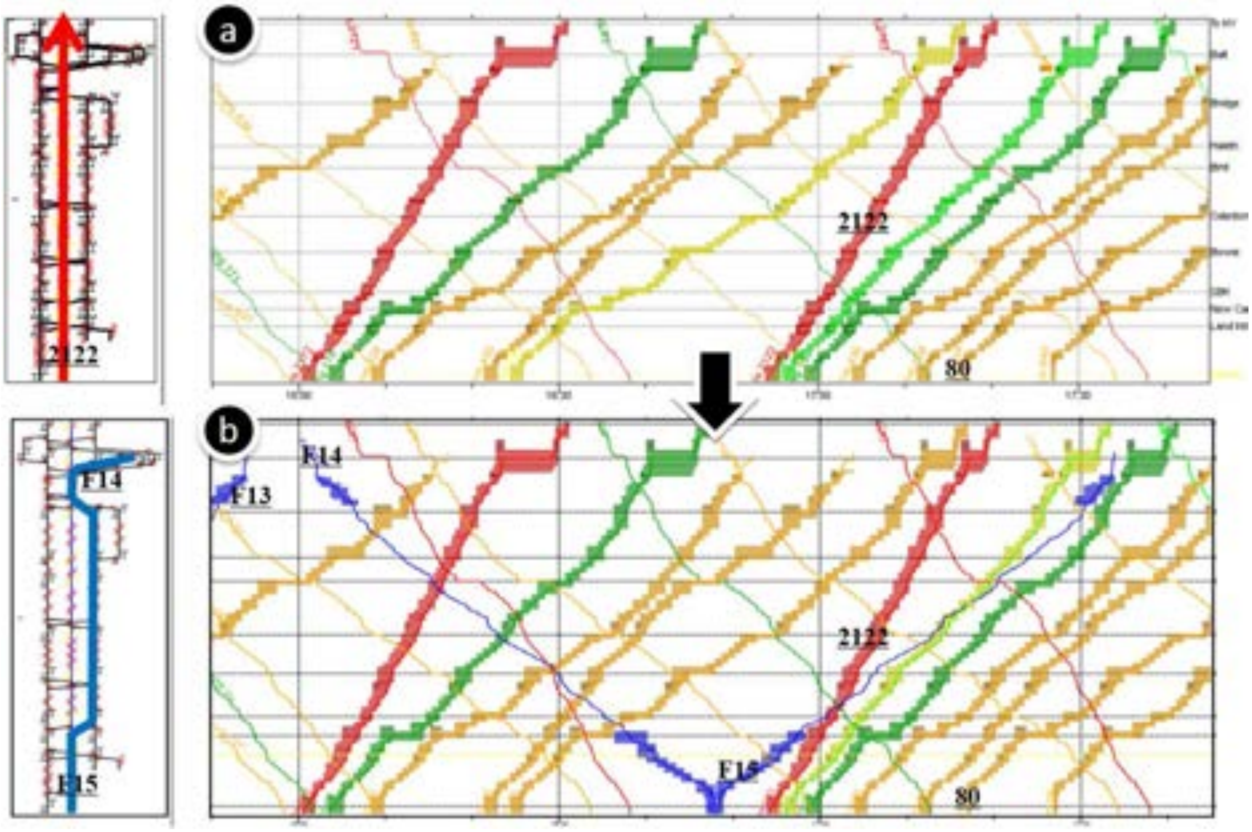

Figure 22 - Snapshot of (a) fully directional schedule (Scenario 2), and (b) an example of new freight trains (shown in blue color) added to the same directional pattern schedule using Track #3 *(Note: Routes for Acela #2122(in red) and freight trains F14 and F15(in blue) are presented on the left side of Figure "a" and "b", respectively. Trains F14 and F15 use the same route in both directions)*

4-2 Review of Michigan Scenarios and Results

Unlike a multiple-track corridor, there are fewer alternatives to adjust the operations on a single track corridor. This part of research evaluates the scenarios to improve the capacity of Michigan accelerated corridor between Detroit and Jackson, most of which is a single-track corridor. The main objective was to evaluate the effects of rescheduling practices when no changes are allowed to the existing infrastructure (2014 track and station layouts were used). Several parameters, such as number of new trains, stop pattern and dwell time, schedule deviation, and track occupancy level before and after rescheduling, were used in the analysis. Michigan Scenario 1 represents the initial schedule, and Scenarios 2 and 3 represent services added to the corridor.

4-2-1 Scenario 1: Base Model (Initial Schedule)

4-2-1-1 Schedule Replication

MDOT provided an RTC database for the initial train schedule (Scenario 1) for the Detroit-Jackson corridor. The RTC database was replicated in RailSys to evaluate train performance and LOS parameters of initial schedule (Scenario 1) and the new adjusted schedules (Scenarios 2 and 3). Figure 23 shows both the initial schedule in RTC format (top) over 24-hour time period and the RailSys replicated schedule (bottom). The replicated train schedules matched the same stop pattern, order of trains, and had similar arrival/departure times as the initial RTC schedule. Similar to the NEC case study, there were some deviations between arrival/departure times (approx. one- to seven minutes), when comparing RTC to the RailSys results. The deviations of simulated train running times, particularly for heavy freight trains, were caused by the differences between rolling stock and signaling features and equations in RailSys versus RTC. These deviations, however, did not affect the train order, stop pattern and routing options of the RailSys train schedule as the time window (buffer) between requested train departures was large enough to accommodate the deviations caused by the conversion to RailSys.

It should be noted that several local freight trains in the RTC database operated between Milwaukee junction and industrial tracks near the Detroit yard. These trains affected the Detroit-Jackson mainline operations. Though these trains were included into the RTC database and the respective results such as animation, they were not illustrated in the top part of Figure 23 because they were included in a separate division of RTC stringline (Detroit-Pontiac division). When replicating the RTC database in RailSys, all respective freight movements crossing the Detroit yard that may affect the interlocking and switching activities were included in the RailSys timetable (marked by a rectangle in Figure 23-b). In addition, there are three local (switcher) freight trains running back and forth between Jackson and Lake yards which could not be illustrated in RailSys as similar as RTC, due to their switching activities along the yard tracks and long waiting time through the end of timetable horizon. For instance, RTC shows part of the switcher train stringline at both the beginning and end of the day, while RailSys shows it only at the end of the day[4]. In addition, the switcher trains, highlighted by "*" on Figure 23, may have schedule deviation in their departure times depending on different weekday hours.

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[4] A train departed at 11:30 pm from Jackson, arrived around 11:55 pm to Lake and stayed there until 2:10 am next day, is shown in both sides of the RTC stringline (late night and early morning times); while RailSys only shows it once in the stringline (late night departure).

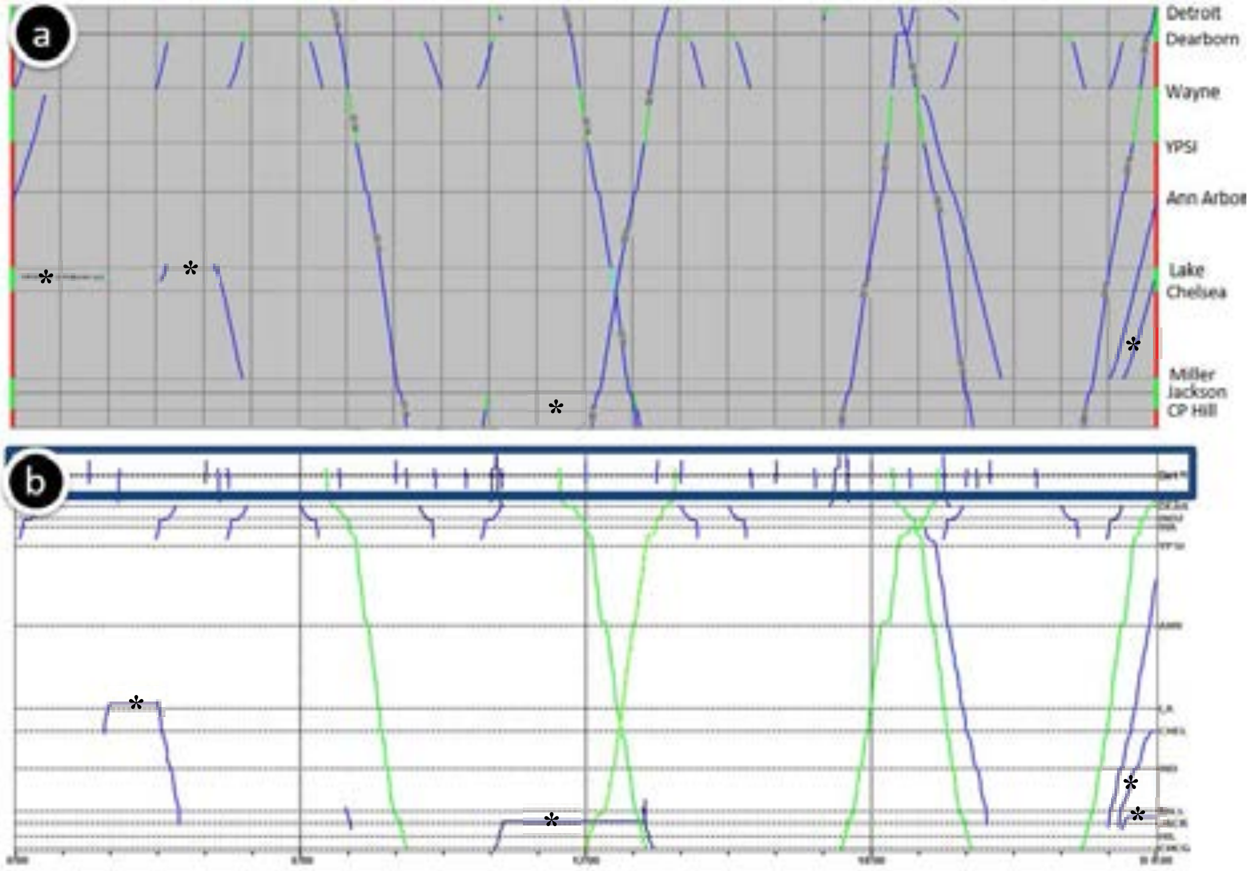

Figure 23 - (a) Initial schedule in RTC, (b) replicated schedule in RailSys *(Note: Amtrak and freight trains are represented in RailSys by green and blue lines, respectively)*

4-2-2 Scenario 2, Adding Freight Services

In Scenario 2, rescheduling was used to enable the addition of twelve new freight services to the initial schedule. New freight trains had the same characteristics as one of the existing freight services (6,250 gross tons and two diesel-electric engines). Eastbound and westbound trains were equally dispatched in both directions every three hours from 4:00 until 23:00. HOTS Model (Same-order approach) was used to provide a conflict-free train schedule and RailSys was applied to validate the new schedules. For rescheduling purposes, the HOTS flexibility parameters were defined to minimize passenger train schedule changes and priority of intermodal trains was set higher than other freight trains. Table 16 presents the primary flexibility parameters of HOTS model defined for Scenario 2.

Table 16 - Primary flexibility parameters of HOTS model defined in Scenario 2 of Michigan case study

Parameter	Passenger	Intermodal	Freight	New Freight
Min. requested dwell time (min)[1]	1	0	0-180 [2]	0
Max. allowed dwell time (min)[3]	15	20	20-260 [2]	20
FDB[4] (min) [5]	0	60	60	0
FDA[6] (min)	30	360	360	360
Headway (min)	2	3-4 [2]	3-5 [2]	5
Priority of train	5	3	2	2

1: *Minimum dwell time for planned stop points, otherwise zero*
2*: Varied based on different train and its configuration*
3*: Similar values for each type of train at all stations*
4: Maximum early departure deviation
5: FDB was assumed as zero for the origin stations (i.e. initial schedule maintained)
6: Maximum late departure deviation

Of the flexibility parameters presented in Table 16, the minimum requested dwell time of trains remained identical with the initial schedule, but maximum allowed dwell times had higher values to provide more flexibility for HOTS model to find a feasible solution. The FDB flexibility parameters were assumed "0" for passenger trains and new freight trains at all stations to prevent early dispatching of these trains. However, other trains could be dispatched earlier at the planned stops, excluding the origin station. There were no intermediate stops for new freight trains and they all operated between Jackson and Wayne yards.

Figure 24 shows a 24-hour time period of the initial schedule (top) and Scenario 2 (bottom). As shown in the figure, new freight services were successfully added with a few minor schedule deviations to existing trains (schedule deviation highlighted with rectangles). It should be noted that only 11 of 12 new planned services could be added to the schedule, if they were dispatched every three hours (simultaneously to both directions). Due to traffic congestion at the end of the day (from approx. 21:00 to 23:00), the 12th freight train could have caused major schedule deviations for the existing trains, which was not allowed in the HOTS model. Thus, it was eliminated from the final schedule to maintain the defined scheduling parameters of HOTS. Also, as illustrated in the Figure 24 -b, some of the new freight trains (as well as two existing passenger services) meet each other between the Chelsea and Lake stations (highlighted in circles). This approx. 5-mile section is double-track; allowing non-conflicting meets of opposing trains.

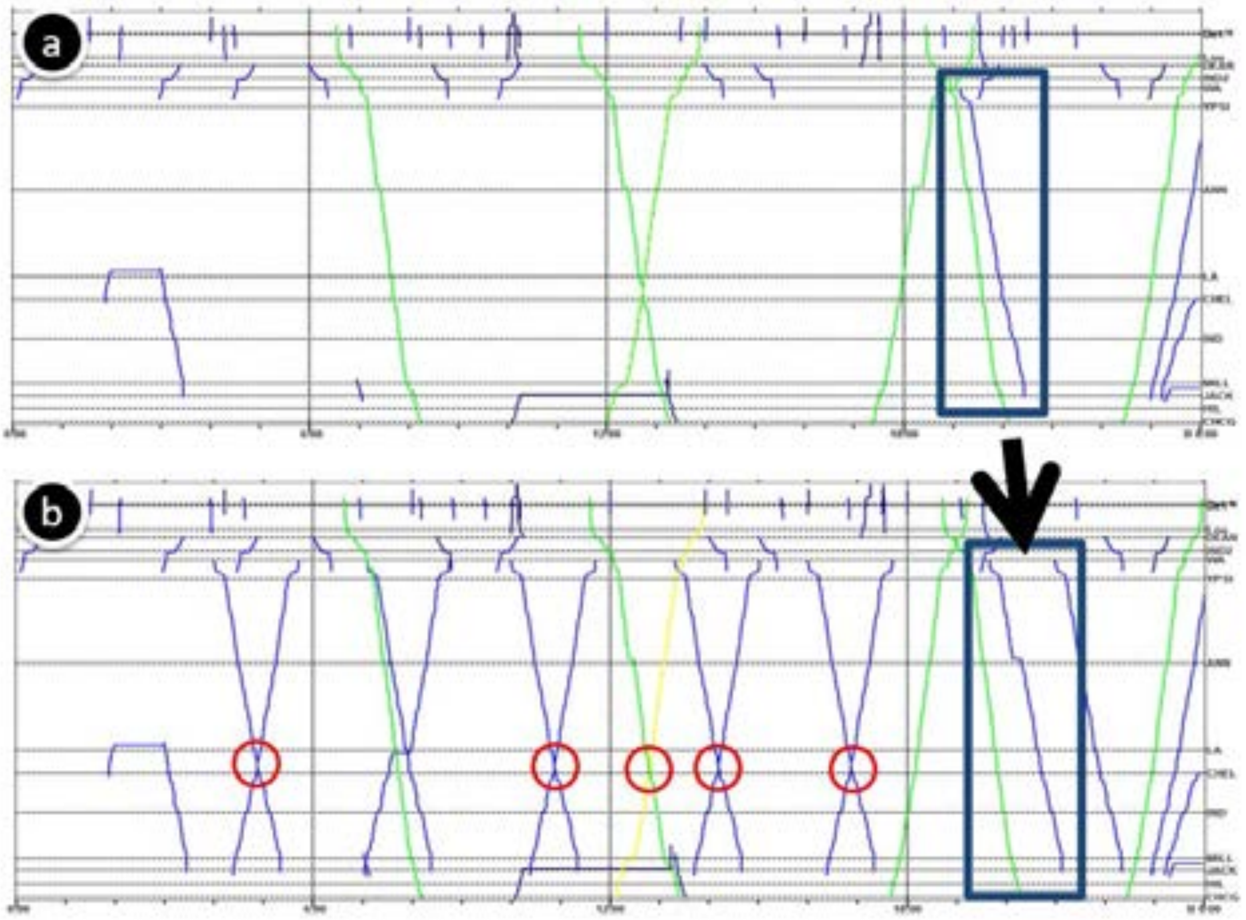

Figure 24 - (a) Initial schedule, (b) modified by HOTS model to include new freight trains (Scenario 2)
(Amtrak: Green, Freight: Blue)

4-2-3 Scenario 3: Adding New Commuter Services

Michigan Scenario 3 added ten new commuter trains to the initial schedule. The new commuter services are planned to begin operations in 2017, after infrastructure improvements to the Detroit - Ann Arbor segment are completed. Those improvements were excluded in this scenario (existing 2014 infrastructure was used instead). The Scenario 3 was simulated in HOTS Model (Same-order approach) to provide a conflict-free train schedules. The HOTS model flexibility parameters settings were the same as in Michigan Scenario 2 to avoid any major passenger and new commuter train schedule deviation from initial schedules. However, a higher priority value was defined for commuter trains compared to the other types of trains, since schedule deviation and non-punctuality of service are more unacceptable for commuter trains compared to the long-distance passenger trains. Table 17 presents the primary flexibility parameters of HOTS model used in Scenarios 3.

Table 17 - Primary flexibility parameters of HOTS model defined in Michigan case study Scenario 3

Parameter	Passenger	Intermodal	Freight	New Commuter
Min. requested dwell time (min)[1]	1	0	0-180 [2]	1
Max. allowed dwell time (min)[3]	10	20	20-260 [2]	5
FDB[4] (min) [5]	0	60	60	0
FDA[6] (min)	30	360	360	30
Headway (min)	2	3-4 [2]	3-5 [2]	2
Priority of train	5	3	2	7

1: *Minimum dwell time for planned stop points, otherwise zero*
2*: Varied based on different train and its configuration*
3*: Similar values for each type of train at all stations*
4: Maximum early departure deviation
5: FDB was assumed as zero for the origin stations (i.e. initial schedule maintained)
6: Maximum late departure deviation

Figure 25 demonstrates a 24-hour time period of the Michigan Scenario 3 in comparison to Scenario 1 on top. As shown in the figure, adding new commuter services was successful with minor schedule deviation for a few passenger and commuter trains. However, one of the freight trains (highlighted in the figure by rectangle) was rescheduled approx. 60 minute earlier to provide more room for new commuter services.

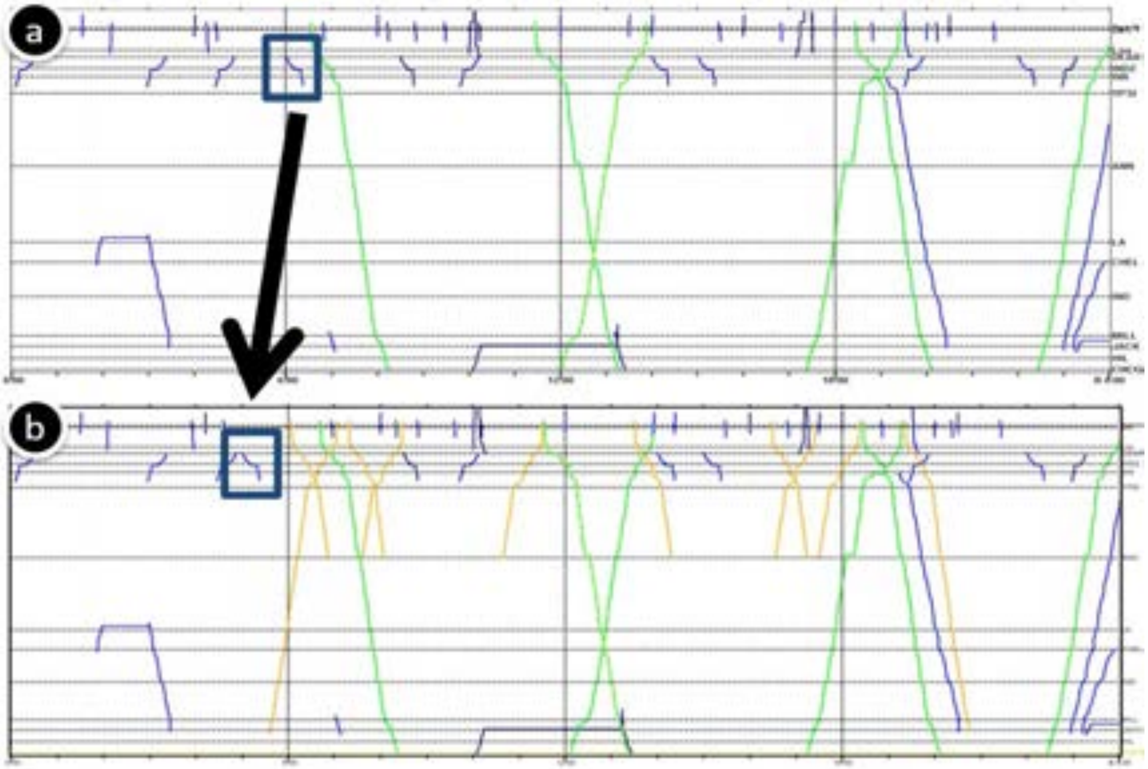

Figure 25 - (a) Initial schedule, (b) modified by HOTS model to include new commuter trains (Scenario 3)
(Amtrak: Green, Freight: Blue, Commuter: Orange)

In another model run, the priority of passenger trains was set higher when compared to the commuter trains. The resulting new schedules (presented in Figure 26) were similar to the previous run that assigned a higher commuter train priority. Although the average schedule deviations for passenger and commuter trains in new model run were approximately 50% and 120% higher, respectively, than the initial model run of Scenario 3. Thus, we concluded that the initial iteration of Scenario 3 with a higher priority for commuter trains provided better results with lower schedule deviation.

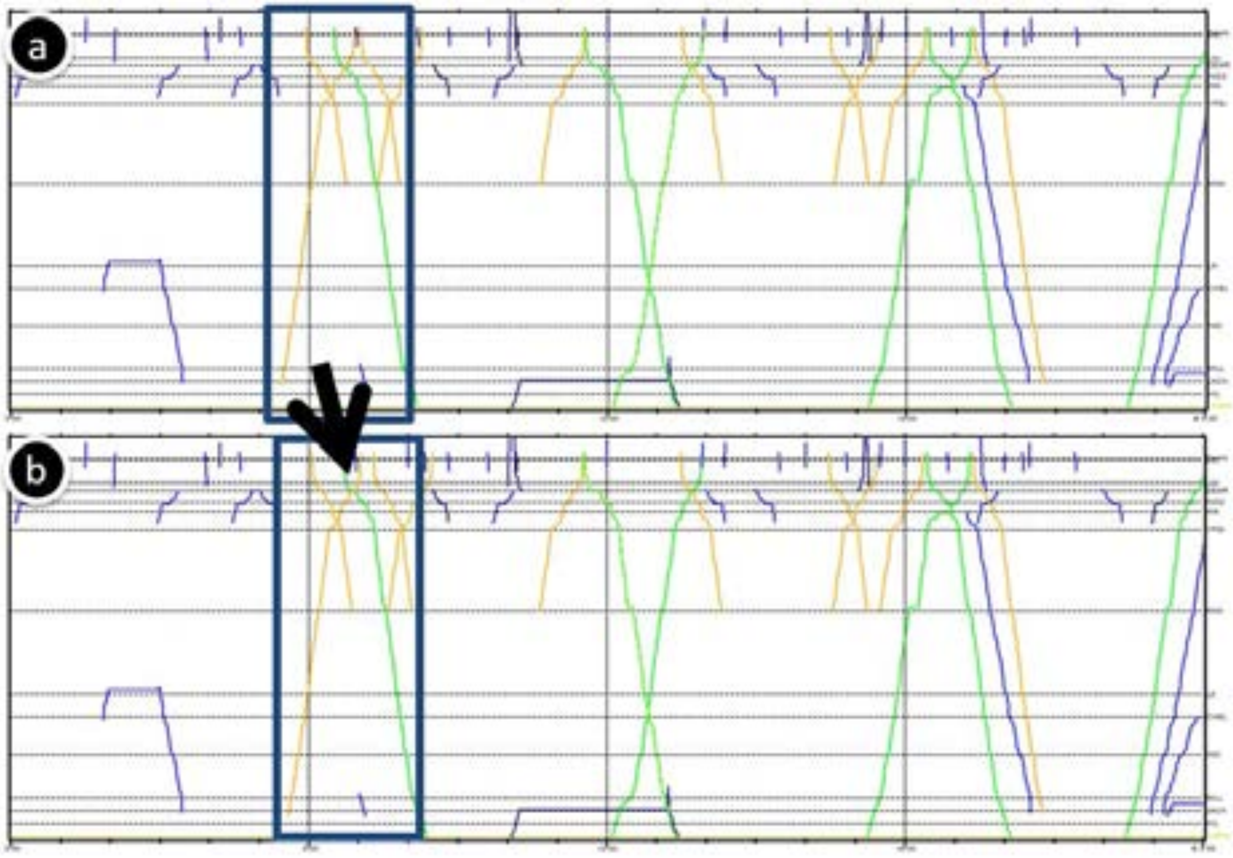

Figure 26- (a) Scenario 3 with higher priority for commuter, (b) modified with higher priority for passenger trains *(Amtrak: Green, Freight: Blue, Commuter: Orange)*

4-2-4 Comparison between the Scenarios

Both scenarios of the Michigan case study were conducted to evaluate the rescheduling practices when adding new freight (Scenario 2) or commuter services (Scenario 3) on the existing infrastructure. Various scheduling parameters, such as deviation from initial schedules, stop pattern, dwell time, and track occupancy status were used to compare the results.

4-2-4-1 Stop Pattern and Dwell Time Analysis

Table 18 compares the stop and dwell time records of all scenarios. As presented, both Scenarios 2 and 3 have higher values than the initial schedule. The maximum dwell time observed for existing passenger trains and new commuter services did not exceed three minutes (approx. 90% of them were less than one minute). New freight services experienced four new stops with maximum dwell time of seven minutes, as HOTS resolved conflicts between trains.

Table 18 - Comparison between stop pattern and dwell time parameters for scenarios in Detroit-Jackson case study

Parameters	Scenario 1 (Initial schedule)	Scenario 2 (New freight trains)	Scenario 3 (Commuter trains 2017)
Total dwell time (min)	619	667	647
Max dwell time (min)	260 [1]	260 [1]	260 [1]
# of stops [3]	23	27	49 [2]

1: *maximum dwell times observed for local freight trains*
2*: because of more planned stops for new commuter services*
3*: either a planned or a meet-pass stop*

4-2-4-2 Schedule Deviation

Table 19 presents the schedule deviations for each train type. The average and maximum deviation for existing passenger trains were 9.7 minutes and 18 minutes, respectively, for Scenario 2, and 3.4 minutes and 11 minutes, respectively, for Scenario 3. However, the schedule deviations for new commuter trains were lower than passenger and freight trains. Since the new freight trains have longer runs, lower priority and slower speed than the commuter trains, adding new freight trains most likely caused longer schedule deviations. Based on the results, minor changes to the current train schedules may provide room for additional freight or commuter trains on existing infrastructure, in our case up to 11 additional freight or 10 additional commuter trains. However, these additions may increase the risk of traffic congestion and train delays, if any service interruption happens, particularly for the freight services between Detroit and Jackson yards.

Table 19 - Comparison between schedule deviation records to the initial schedules (Michigan Scenario 1)

Scenario	Train Type	Average deviation (Minutes)	Max deviation (Minutes)	Std. dev.
Scenario 2	**Existing passenger**	9.7	18	0.2
	Existing Freight	0.5	42	0.4
	New Freight	13	120	10.9
Scenario 3 *(Higher priority for Commuter)*	**Existing passenger**	3.4	11	0.1
	Existing Freight	0.3	60	0.5
	New Commuter	2.6	15	2.3

4-2-4-3 Track Occupancy Level

Figure 27 shows the average track occupancy percentage per day at the stations (number of hours that the busiest track of each station is occupied by different trains, divided by 24 hours) as derived from RailSys reports. Figure 27 also includes the average track occupancy for the single-track main line segment between Wayne and Dearborn (identified in the figure as "Main Line"), which has the highest daily traffic of the corridor. The average track occupancy of Scenarios 2 and 3 is higher than the initial schedules at most locations, due to added train volumes. However, depending on the type and origin/destination of additional traffic (new freight vs. commuter services), the track occupancy level is different for several stations in Scenario 2 vs. Scenario 3 (Figure 27). For instance, Dearborn station track is approx. 3% higher occupancy level for new commuter trains, because almost all commuter trains stop at this station, while added freight services maintained the previous average occupancy level (no planned stops at Dearborn). On the other hand, Wayne has higher average occupancy level for new freight service, because it is one of the origins/destinations of new freight services. Similar trends were observed for main line average occupancy level, though the commuter trains cause slightly higher values than freight trains. Overall, the highest value of average daily occupancy level is under 14% (observed in Jackson) in all scenarios. This is well below the average track occupancy threshold of 60-70% as recommended by the rail industry [4, 41, 42].

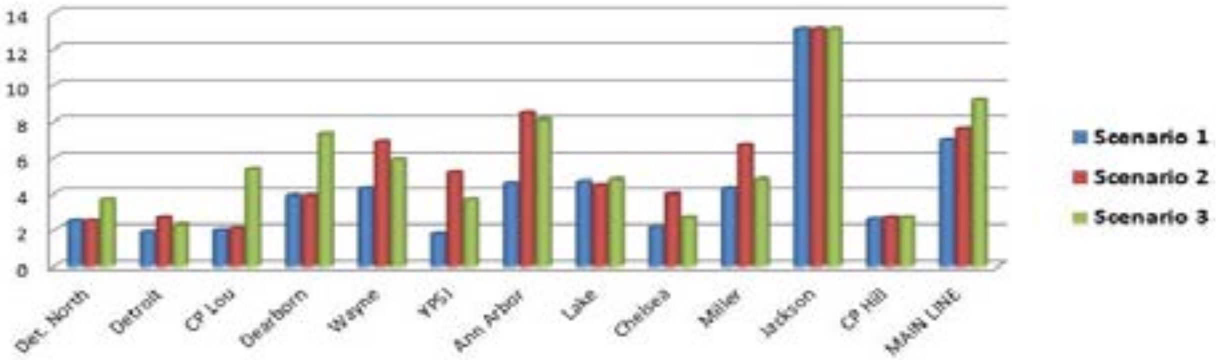

Figure 27- Average track occupancy percentage per day at different stations (busiest track) for each Michigan scenario

The peak hour track occupancy (Figure 28) provides a better metric to evaluate the maximum track occupancy levels, as it can identify potential bottlenecks.

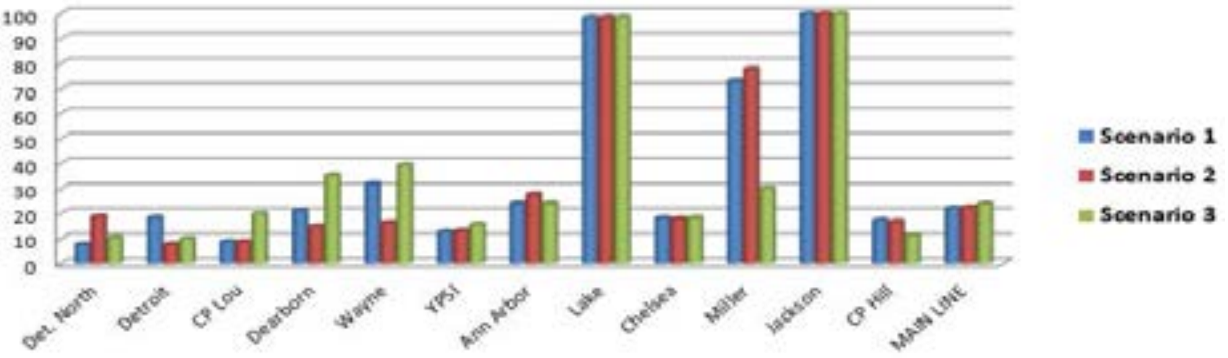

Figure 28 - Max track occupancy percentage for peak hour at different stations (busiest track) for each scenario

Even with more train services, the value of maximum peak hour track occupancy levels have been reduced at some stations, due to rescheduling practices that have distributed the traffic flow from the peak hours to other adjacent time slots. However, there are some stations under Scenario 3 (e.g. CP Lou, Dearborn and Wayne) where maximum track occupancy levels have been increased due to new services.

Based on Figure 28, track occupancy level is a concern at Jackson and Lake yards (the maximum peak hour track occupancy was close to 100%). The high value of maximum track occupancy level of these stations were caused by local freight trains that occupied at least one arrival/departure track of these two yards for more than one-hour period. Miller, Ann Arbor, Wayne and Dearborn are other stations/yards with high maximum track occupancy levels. Overall, the maximum peak hour track occupancy level along the "Main Line" was between 22% and 24% for all scenarios meaning that the overall capacity utilization of this corridor is still under the threshold value of 60-70%.

4-3 Discussion of Results

This research used two case studies to investigate use of operational management techniques, mainly scheduling to improve the capacity or LOS parameters of shared-use corridors. Three primary scenarios were defined for each case study. The initial schedule (Scenario 1) was considered as a benchmark, representing current operations, while Scenarios 2 and 3 applied commercial simulation tools and HOTS model to get optimized schedules. Table 20 summarizes all scenarios developed in the research.

Table 20 - Summary of developed scenarios over the selected case studies

Case Study	Scenario	Objective	Methodology Approach	Final Results
NEC	**1- Initial schedule**	**To provide a benchmark schedule**	Combined Simulation	Replicated schedules in RailSys and OpenTrack
	2- Heuristic scenario	To develop a fully directional pattern **heuristically**	Combined Simulation	Converted to fully directional operations (time consuming approach, required expertise and construction of island platforms at selected stations)
	3- HOTS scenario	To develop a fully directional pattern using **"HOTS model"**	Combined Simulation + HOTS model	Converted to fully directional operations (quicker and more convenient than Scenario 2, required construction of island platforms and overtaking at stations)
MI	**1- Initial schedule**	**To provide a benchmark schedule**	Combined Simulation	Replicated schedules in RailSys
	2- Adding freight trains scenario	To add **"new freight trains"** to the initial schedule	Combined Simulation + HOTS model	11 new freight trains successfully added to the service
	3- Adding commuter trains scenario	To add **"new commuter trains"** to the initial schedule	Combined Simulation + HOTS model	10 new commuter trains successfully added to the service

As shown in Table 20, Scenario 1 of NEC case study represented the initial (existing) schedule of corridor under non-directional operation pattern, Scenario 2 applied a heuristic methodology to convert the initial schedule to a fully directional pattern, and Scenario 3 (further divided to three sub-scenarios) performed the same conversion as Scenario 2, but used the HOTS model. While the procedure of running the sub-scenarios under Scenario 3 with HOTS model was faster and more convenient from research perspective, the Heuristic model (Scenario 2) performed slightly better in terms of evaluated parameters. Scenario 2 maintained the same number of stops as the initial schedule, but the maximum dwell time and total dwell time were shorter than in other scenarios. It also provided lower average schedule deviation, although the maximum schedule deviation was higher. Due to its better overall performance, Scenario 2 (heuristic model) was used for non-directional/directional performance comparison.

Comparison between Scenario 1 (non-directional operation) and Scenario 2 (fully directional operation) demonstrates that the average train speed was improved under Scenario 2, but the total delay of trains and the average track occupancy for Track #2 were increased due to the shifting of all train operations from Tracks #3 and #4 to Track #2. The study resulted in higher capacity utilization on Tracks #1 and #2 and opened up capacity for 22 new freight services (using Track #3) without any service interruption for the existing passenger and commuter trains.

While the implementation of directional approach in this multiple-track case study would require construction of side or island platforms at intermediate stations to provide platform access for rerouted trains, it might be a noteworthy alternative to address corridor congestion. In a larger perspective, the research validates some of the perceived capacity benefits of directional operations and suggests that increasing the number of directional trains through rerouting, rescheduling, or combined rerouting/rescheduling efforts is worth analyzing when searching for alternatives toward improved corridor performance.

In Michigan case study, Scenarios 2 and 3 used HOTS model and RailSys simulations to evaluate the effects of new freight (Scenario 2) and new commuter (Scenario 3) services to the corridor. Overall, both Scenarios 2 and 3 of Michigan case study were successful in adding additional services after rescheduling (11 new freight and 10 new commuter services, respectively). In both scenarios, the average and maximum schedule deviation for existing passenger trains were 9.7 minutes and 18 minutes respectively for Scenario 2, and 3.4 and 11 minutes respectively for Scenario 3. The schedule deviations for new commuter trains were smaller than the passenger and freight trains. The track occupancy levels (both average per day and maximum occupancy levels per peak hour) were analyzed at all stations and the main line. It was concluded that the average track occupancy levels for all stations were slightly increased in both Scenarios 2 and 3. However, the maximum track occupancy level during peak hour was maintained or reduced at some stations, since the main line rescheduling practices redistributed the traffic flow from peak hour to less crowded times. Overall the maximum track occupancy level of the main line under Scenarios 2 and 3 (24%) was still well below the 60-70% capacity utilization threshold recommended by rail industry.

5 SUMMARY AND CONCLUSIONS OF THE RESEARCH

This research was tasked to investigate the use of operational management techniques on existing infrastructure to improve the capacity utilization and/or LOS parameters along shared-use rail corridors. Two cases studies, a multiple- track corridor (Washington, DC – Baltimore, MD segment of NEC corridor) and a single-track corridor (Detroit – Jackson, MI accelerated passenger corridor) were using HOTS model, a new analytical rescheduling model, as well as in RTC, RailSys, and OpenTrack simulation packages.

Chapter 1 explained the background of this research discussed capacity and respective methodologies and tools available for evaluating the capacity and LOS parameters. It was found that:

- There are multiple definitions of railroad capacity.
- There are various techniques, tools and metrics to evaluate the capacity based on the objectives, operational characteristics and the scope of the given study.
- The capacity analysis approaches and methodologies are most commonly divided into analytical and simulation methods, as well to a "combined" approach that uses both analytical and simulation methods in a hybrid pattern.
- There are several differences between the U.S. and European rail systems (such as structured operations philosophy in Europe vs. unstructured operations in the U.S. rail environment) that affect the approaches, tools, and outcomes of capacity analysis.
- Europe tends to use timetable based simulation approaches for capacity analysis, while unstructured U.S. operations warrant non-timetable based analysis.
- The two primary types of operational changes (based on train characteristics, and train rescheduling) are common applications to provide further improvement through the LOS and capacity utilization.
- The research focused on rescheduling by applying timetable management techniques using simulation or combined analytical-simulation methodologies.
- A new hybrid analytical-simulation model, called "Hybrid Optimization of Train Schedules" (HOTS) was used in this research to facilitate the analysis of running different rescheduling scenarios and comparing the results in more convenient way using optimization algorithm.

Chapter 2 explained the case studies selected for this research, as follows:

- Both case studies required similar database categories (infrastructure, signaling, rolling stock, and signaling system) in the simulation tools but maintained different characteristics and specifications.
- The initial database for both case studies was provided in RTC format and replicated in RailSys and OpenTrack for further analysis.

Chapter 3 explained the required steps and challenges to replicate the RTC database in RailSys and OpenTrack as well as described the research methodology:

- The research methodology included two approaches: combined simulation (RTC+Railsys/OpenTrack), and combined simulation + HOTS model approach.
- Each tool used in the study had certain strengths that justified their use:
- RTC: Extensive U.S. signaling and rolling stock database, animation features, format of original database.
- RailSys/OpenTrack: various rescheduling and rerouting features to automatically adjust the train schedules

- HOTS model: Customized rescheduling features are: quicker application, and optimization algorithm
- Duplicating the RTC database in other simulation tools to conduct the combined simulation approach was time consuming and challenging particularly in terms of converting the signaling and rolling stock characteristics.

Chapter 4 explained the case studies scenarios for improving the capacity or LOS parameters:

- Three primary scenarios were defined for each case study.
- The current/initial schedule (Scenario 1) was considered the benchmark for evaluating the other scenarios, while Scenarios 2 and 3 applied simulation tools (and HOTS model) for verifying rescheduling practices over the initial schedule (Scenario 1).
- In the NEC case study:
    - Both Scenarios 2 and 3 successfully provided a fully directional pattern after rerouting and rescheduling, but the results of Scenario 2 (Heuristic) were better overall in terms of rerouting/rescheduling criteria such as the schedule deviation, maximum dwell time, total dwell time and avoiding overtaking options.
    - Scenario 2 also required additional side/island platforms at stations to provide passenger access for the trains on Track #2 as well as rearrangement of crossover layout.
    - The "average track occupancy level" of Track # 1 and #2 in fully directional operations were increased slightly (0.3% and 5.0% respectively). However, the occupancy level of Track #3 and #4 in directional pattern were reduced to 0% from 5.7% and 7.0%, respectively.
    - The "maximum track occupancy level" was maintained for Track #1, while it had increased for Track #2 (45.5% vs. 36.9%), mainly due to increased number of trains using Track #2 under directional operation pattern.
    - Under the directional approach, Tracks #3 and #4 have no traffic making them available for new traffic.

- In Michigan case study:
    - Additional services were successfully added to both Scenarios 2 and 3 (11 new freight and 10 new commuter services, respectively), based on applying minor schedule changes of up to 18 minutes and 11 minutes for Scenario 2 and 3, respectively.
    - The scenario with a higher priority for commuter trains performed better and had a smaller schedule deviation than the scenario with higher priority for passenger trains.
    - In Scenarios 2 and 3, the average track occupancy levels slightly increased in all stations after adding new services.
    - The maximum track occupancy levels per peak hour were not increased at certain stations as the rescheduling practices shifted trains from peak hour to other times.
    - New freight trains with longer runs, lower priority and slower speed in comparison to the commuter and passenger trains could most likely cause longer schedule deviations.

In conclusion, the research revealed that:

- Both approaches (combined simulation and combined simulation + HOTS model) were successful in evaluating the respective scenarios.
- HOTS model could facilitate the simulation procedure to improve the rescheduling results and requires less user expertise than the combined simulation approach. However, several iterations and adjustment of the user-defined parameters, such as min/max allowed dwell time and

early/late departure time deviation, may be required to provide comparable results with heuristic methods.

- Several parameters can be analyzed to evaluate the rescheduling practices for improving the capacity and LOS, but the following parameters may have higher impact on the analysis:
    - Schedule changes (average schedule deviation, stop pattern, max dwell time, and total dwell time). Some of these are “given” values and some are simulation outputs.
    - Maximum track occupancy level (during peak hour) as it can identify the bottlenecks of the corridor
    - Train delay analysis before and after rescheduling
- Timetable changes and may increase the risk of traffic congestion and train delays, if recovery time is not considered in the new schedule.
- Incorporating the uncertainties of the daily operations and considering the network impact of rescheduling practices can provide more robust and reliable train schedules and reduce the risk of further service interruption.

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APPENDIX - PROFESSIONAL ADVISORY COMMITTEE MEETING SCHEDULE AND MINUTES

PAC Meeting, Feb. 5, 2015 10-11 AM

Present: Pasi Lautala, Hamed Pouryousef (Michigan Tech.)

PAC Committee (via Webconf):

Present: April Kuo (BNSF), Mark Dingler (CSX), Davis Dure (AMTRAK), Arun Rao (WisDOT)

Absent: Joern Pachl, Mohammed Alghurabi

Recoded meeting is available in the following address:

https://drive.google.com/file/d/0BzqwZZQTbIO1WUEzOFdiWnZ4eVU/view?usp=sharing

Meeting Minutes:

- Pasi Lautala discussed the project background and tasks/schedule.
- Hamed Pouryousef presented alternative operational management technique ideas and scenarios proposed for the project and provided a brief overview of Hybrid Optimization of Train Schedule (HOTS) model.
- Davis Dure requested clarification of non-timetable based and timetable based terminology for the simulation packages (explained by Hamed).
- Mark Dingler inquired on considering the challenges of yard/siding limitation and capacity issues when changing train characteristics (length, weight, consists).
- April Kuo asked whether any crew management features has been considered in the HOTS model, Hamed answered: “No”, only train scheduling parameters have been developed in the model.
- Hamed clarified the rerouting and rescheduling aspects of the HOTS model, as requested by April.
- Hamed and Pasi emphasized that in this project it is assumed that further operational changes will be applied on the existing infrastructure (no new infrastructure construction) to evaluate how much additional capacity and operational improvement can be obtained without any major capital investment.
- Davis mentioned that it is difficult to justify the impact of operational changes on a single section without looking at the entire corridor (beyond the project case studies). Pasi and Hamed agreed, however they mentioned that this project is applying/evaluating a proof of concept and can be expanded to check or validate these impacts over the rest of the NEC and MI corridors.
- Hamed and Pasi asked the PAC members for comments, prioritization, or other suggestions on the alternative operational scenarios identified (slide 13 of presentation). This will guide the decisions on what scenarios get selected for detailed investigations. Some of the topics of interest by PAC members are:

  - April Kuo: Review of operational velocity of trains in case of service interruption
  - Arun Rao: Adding passenger/HSR services to the corridor
  - Mark Dingler: Reliability and robustness of timetable, based on different patterns and scenarios of trains schedule.
- Each PAC member was encouraged to provide additional comments within next two weeks.
- Meeting adjourned at 11:15 EST.
- Next web conference will be on the first week of April 2015. A meeting invitation will be sent in a separate email.

PAC Meeting 2, April 30, 2015 11 am -12 pm EST

Present: Pasi Lautala, Hamed Pouryousef (Michigan Tech.)

PAC Committee (via Webconf):

Present: Mark Dingler (CSX), Davis Dure (AMTRAK), Arun Rao (WisDOT)

Absent: Joern Pachl, Mohammed Alghurabi, April Kuo

Recoded meeting is available in the following address:

https://drive.google.com/file/d/0BzqwZZQTbIO1NHdRVExSQ1VtN3c/view?usp=sharing

Meeting Minutes:

- Pasi Lautala started the meeting by briefing the current progress of the project and what will be included in the presentation
- Hamed Pouryousef presented the research update that included:
  - Brief introduction of the CFIRE research and the HOTS model
  - Brief explanation of the different scenarios of two case studies (NEC, MDOT)
    - Each case study was analyzed based on three main scenarios including the current schedule.
  - The main objective of NEC scenarios was how to convert the non-directional operation pattern of the existing trains to a fully directional pattern and what are the challenges and benefits for the capacity utilization and Level of service parameters
  - The main objective of the MDOT case study was to investigate how many future trains can be added to the current schedule with no infrastructure upgrades.
- Mark Dingler asked if NEC trains have different priority after rescheduling. Hamed explained that they maintained the same priority as in the initial schedule, and as results the schedule deviation from the initial one is larger for those trains with lower priority (e.g. commuters) than those with higher priority (e.g. Acela).

- Davis Dure pointed out a freight train followed by a commuter train in the results of MDOT scenario-3. Hamed agreed that while model doesn't automatically address the order, it would be better in practice to switch the order. Pasi also pointed out about the current structure of HOTS model (deterministic) and mentioned that the future probabilistic edition of model could help the model to avoid such recommendations for the shared-use corridors.
- Davis also explained about the history of the NEC operations, noting that track #3 was used only by freight trains in the past. Hamed pointed out the next step of the research will be evaluating the number of freight trains that could be added to the corridor (on track #3).
- Mark mentioned that there is a coal freight train running during night along the short segment of Bowie-Landover interlocking (near DC) using track #3.
- Davis explained that there is an expansion plan for the entrance tunnel of Baltimore station which can provide direct access between all three main lines and Baltimore station tracks.
- Pasi asked Mark if there is any interest or application of using HOTS model or similar approach of rescheduling along the class 1s corridors. Mark answered that there is not much application of using such rescheduling practices along the CSX network and the schedule is typically enforced by the yard activities and operations. He also mentioned that BNSF may need a rescheduling application around Chicago area (Aurora-Chicago) where they try to provide a specific window for passenger and freight trains with a more homogenous pattern. Application of HOTS or similar model might be beneficial.
- Pasi and Hamed explained that next steps will finalize the current scenarios and prepare the draft final report. The report will be sent to advisory committee review.
- Next (and last) web conference will be set up for the July 2015. A Doodle poll invitation will be sent out in a separate email to finalize the date and time of the next meeting. Draft report will be provided prior to the meeting.
- Meeting adjourned at 12:05 pm EST.

PAC Final Meeting, November 10, 2015 3 am -4 pm EST

Present: Pasi Lautala, Hamed Pouryousef (Michigan Tech.)

PAC Committee (via Webconf):

Present: Davis Dure (AMTRAK), Arun Rao (WisDOT), April Kuo (BNSF), Kelby Wallace (MDOT), Al Johnson (MDOT)

Absent: Joern Pachl, Mark Dingler

Meeting Minutes:

- April inquired, if all signaling systems were implemented in simulations. Hamed replied that yes, but for HOTS, only travel times were extracted for analysis.
- April also inquired, how use of crossovers is determined (how aggressive dispatching used). Hamed mentioned that in heuristic approach, it was all based on user expertise.
- Davis Dure stated his agreement with concluding slides on the research outcomes
- April inquired, if academic papers have been published in journals. Pasi adviced that one paper on combined (hybrid) method has been recently published by Elsevier (link will be sent). Another paper on HOTS model is currently under review by a different Elsevier paper.
- Discussion followed on heuristic vs. optimization models….which should be used. In some cases a combination of tools may provide the best final result.
- Also short discussion on effects of directional approach to LOS values. Hamed and Pasi explained that our comment on potential reduction of LOS due to directional approach was more NEC specific than a general statement.
- Arun inquired, if there were plans to continue the research. Pasi noted that due to Hamed's departure, Michigan Tech lost "much of their expertise" and has no continuing funding. However, Tech is hoping to continue both the research area and collaboration with HAmed and his new employer. Any potential research ideas/funding opportunities are welcome.
- Pasi thanked the committee for taking their time to support the project and asked for them to provide any additional comments/feedback by the end of the week. Copy of the final report will be distributed to the committee members.
- Meeting adjourned at 4:15 pm EST.

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