William W. Hay Railroad Engineering Seminar

Topic #1 *"Introducing Hybrid Optimization of Train Schedule (HOTS) Model as Timetable Management Technique"*

Hamed Pouryousef
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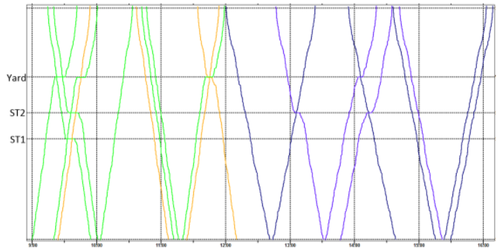

Topic #2 "Hazards Associated with Shared-Use Rail Corridor Operations"

Chen-Yu Lin
University of Illinois at Urbana-Champaign

Date: Friday, April 03, 2015
Time: Seminar Begins 12:20

Location: Newmark Lab, Yeh Center, Room 2311
University of Illinois at Urbana-Champaign

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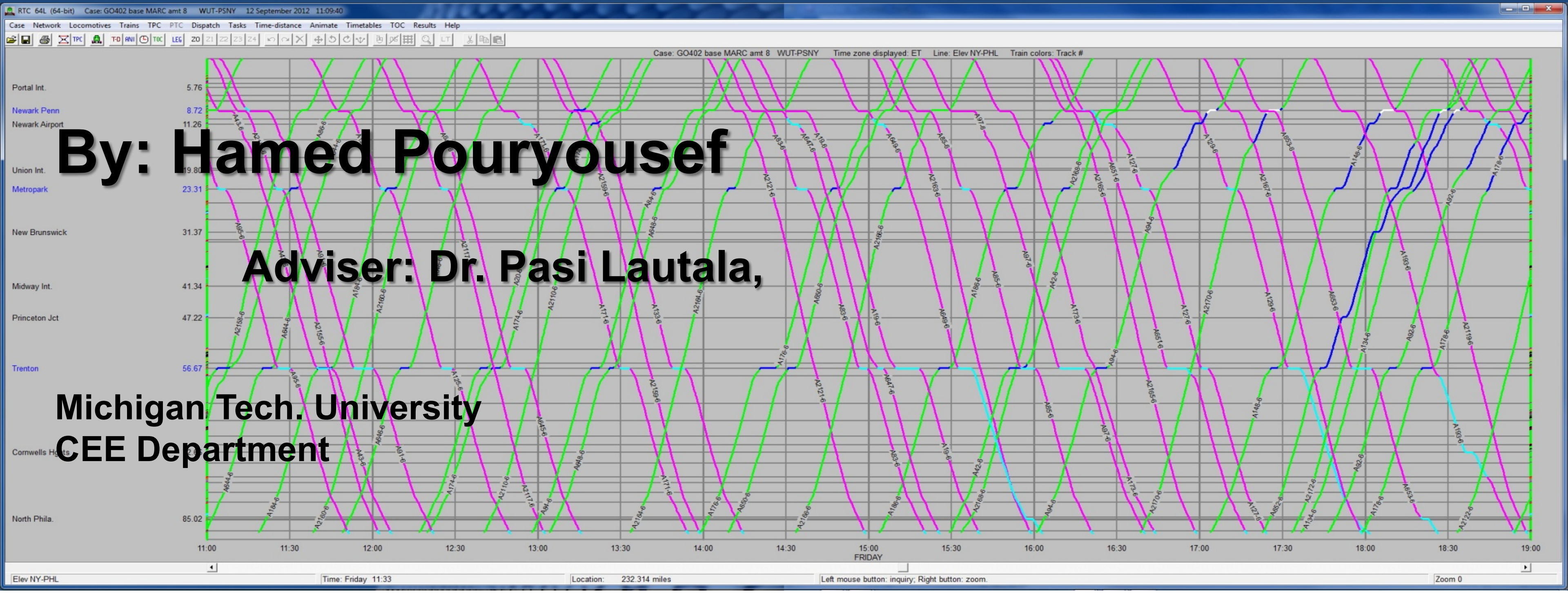
William W. Hay Railroad Engineering Seminar, April 3, 2015

Introducing Hybrid Optimization of Train Schedules (HOTS) Model as Timetable Management Technique



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Background

- **The U.S. railroads are looking for more efficient ways of using capacity, because of:**
  - Growing demand for passenger and freight services
  - Limited capital to expand the infrastructure
- Most challenges on **Shared-use Corridors:**
  - Different types of trains (power, axle load, length, speed and braking regimes)
  - Different signaling and control systems (Generally)

Background

Europe: long history for operating highly utilized shared-use corridors

The U.S.: growing interest to passenger-freight corridors

Network configuration and operation philosophy in the U.S. are different from Europe

Problem Statement:

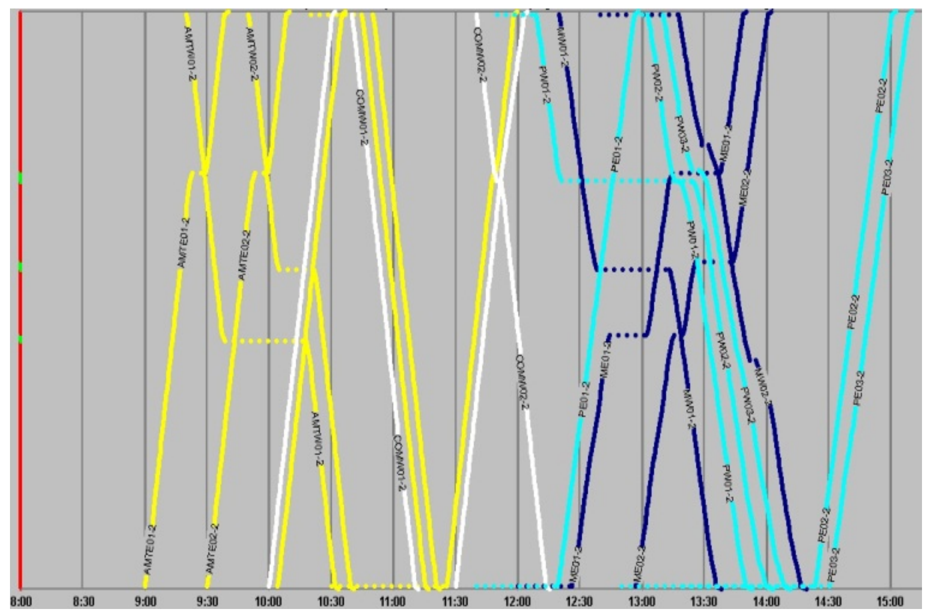
Are there benefits on the U.S. shared-use corridors, (particularly passenger-oriented lines) from using "**Operational Management Techniques**"?

Timetable & Capacity

- **Timetable improvement** (rescheduling, rerouting) is one of the main "Operational Management" techniques to improve the capacity.

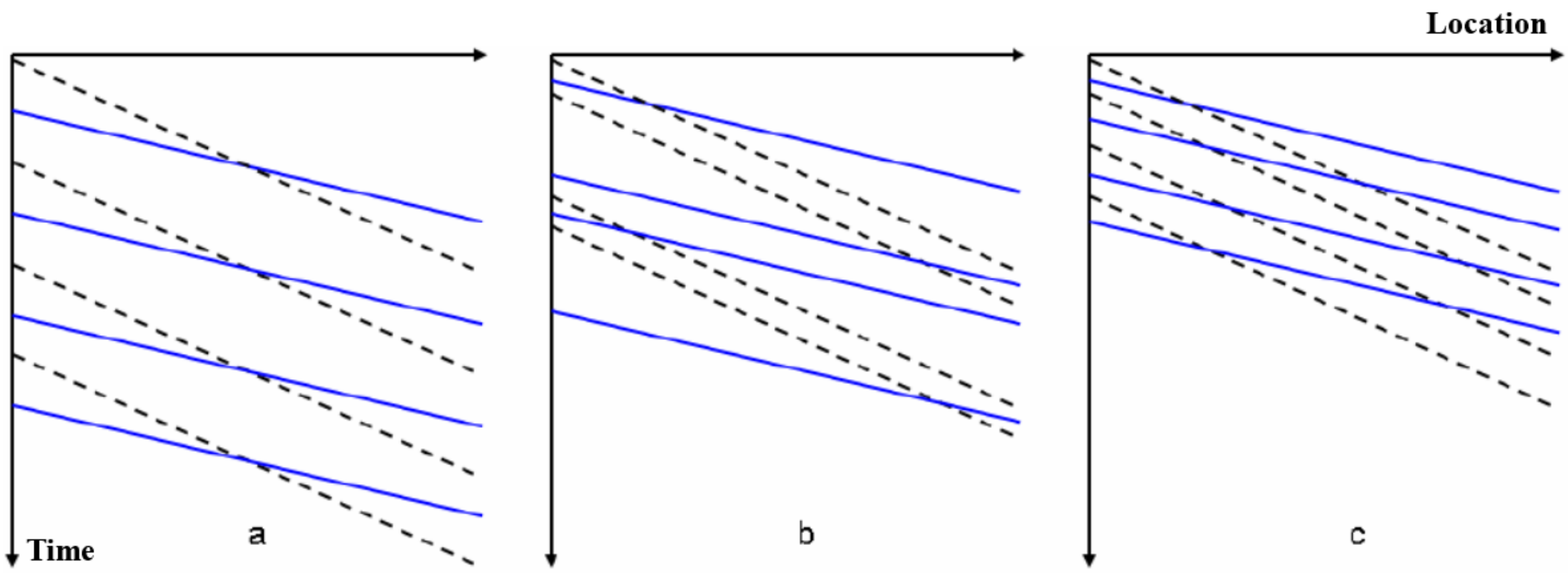
Effective September 10, 2012				
Train Number	350	352	364	354
Days of Operation	Daily	Daily	Daily	Daily
Chicago	7:20A	12:50P	4:00P	6:00P
Hammond/Whiting	7:47A	1:17P	...	...
Michigan City	...	1:57P	...	7:00P
New Buffalo	9:37A	3:09P	6:10P	8:12P
Niles	10:07A	3:33P	6:33P	8:35P
Dowagiac	10:17A	...	6:43P	...
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

Amtrak.com, 2012



Timetable Compression Technique

- Recommended by UIC code 406 in European Practices.
- Modifies the pre-scheduled timetable and reschedules trains as close as possible to each other.
- No changes are allowed on the infrastructure or rolling stock specifications.



(a) Actual timetable for a quadruple-track corridor **(b)**compressed timetable with train order maintained **(c)** compressed timetable with optimized train order (Note: chart layout follows typical European presentation, and solid and dot lines represent different types of trains) (Landex, 2006)

Commercial Software Approach

Testing commercial software with operational management techniques to U.S. environment. Some challenges…

- Most with automatic train conflict resolution or timetable rescheduling/ compression features……**not both**.

- Optimization features typically for either single track or double (multiple) track corridors under **directional operation patterns**.

- Hybrid simulation approach (combining "non-timetable" with "timetable" tools) **time consuming** and requires multiple commercial software

- **No timetable compression** model available in the U.S. rail network (similar to the RailSys compression algorithm for Europe)

Alternative Approach - HOTS

Hybrid Optimization of Train Schedules (HOTS)

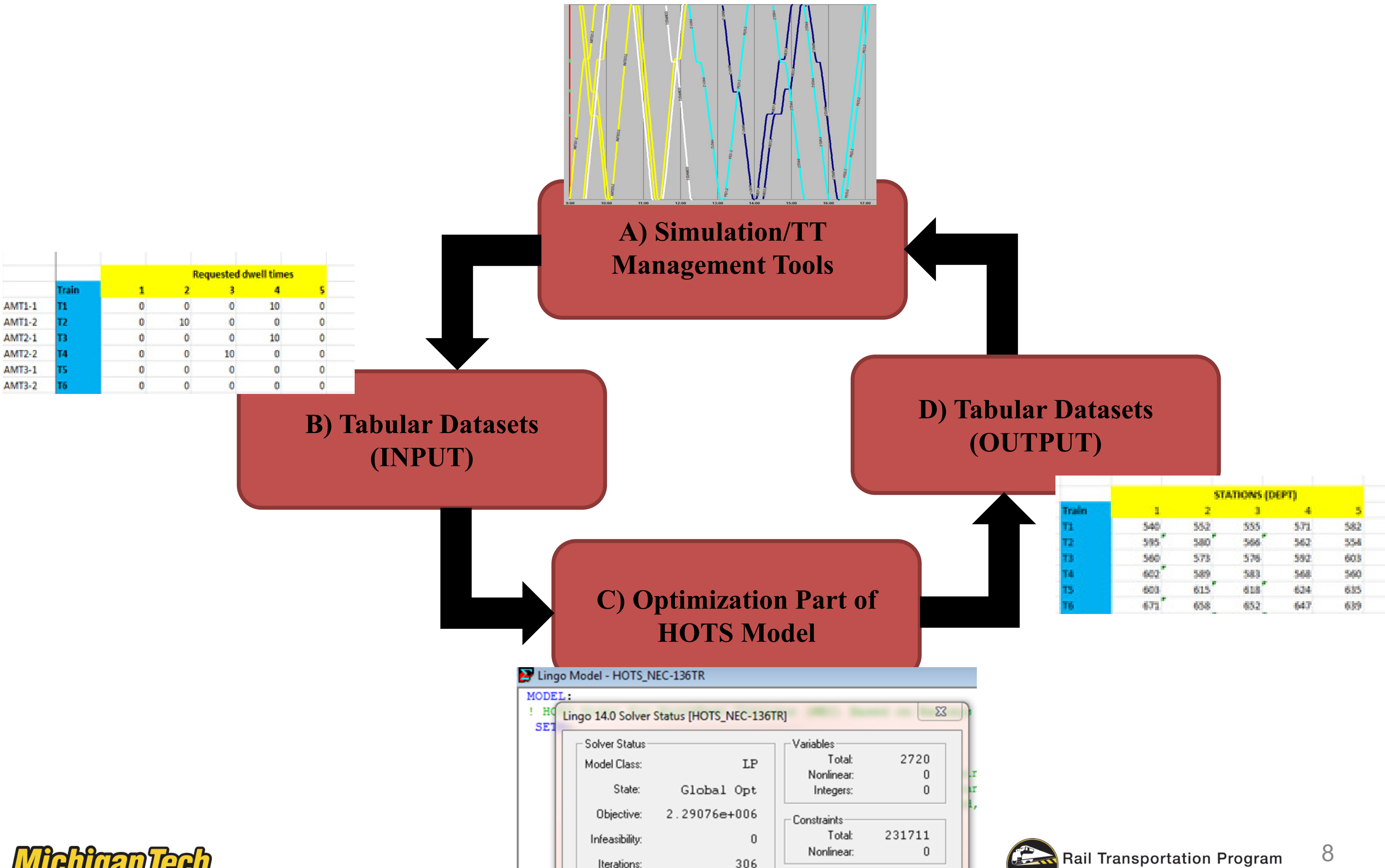
Objective:

- A conflict-free rescheduling model capable for handling different types of rail corridors under both directional and non-directional operation approaches

Methodology:

- **HOTS Model** uses existing simulation software outputs and user-defined parameters to automatically improve the train schedules

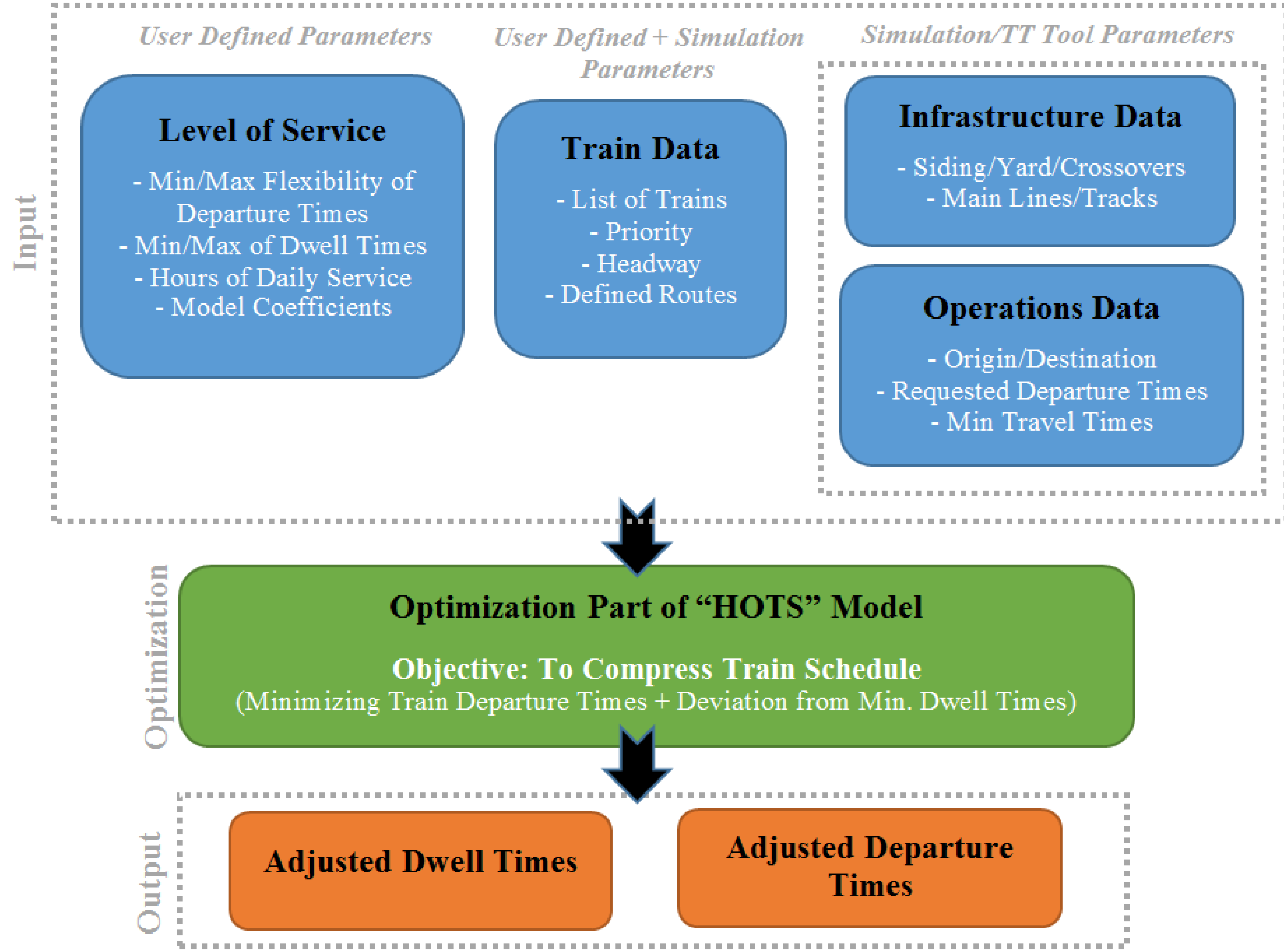
HOTS Model, Main Steps



	Train	Requested dwell times 1	2	3	4	5
AMT1-1	T1	0	0	0	10	0
AMT1-2	T2	0	10	0	0	0
AMT2-1	T3	0	0	0	10	0
AMT2-2	T4	0	0	10	0	0
AMT3-1	T5	0	0	0	0	0
AMT3-2	T6	0	0	0	0	0

Train	STATIONS (DEPT) 1	2	3	4	5
T1	540	552	555	571	582
T2	595	580	566	562	554
T3	560	573	576	592	603
T4	602	589	583	568	560
T5	603	615	618	624	635
T6	671	658	652	647	639

HOTS Model Parameters, Variables, Objective



HOTS Model Input Categories/Sources and the Model Outputs/Objective

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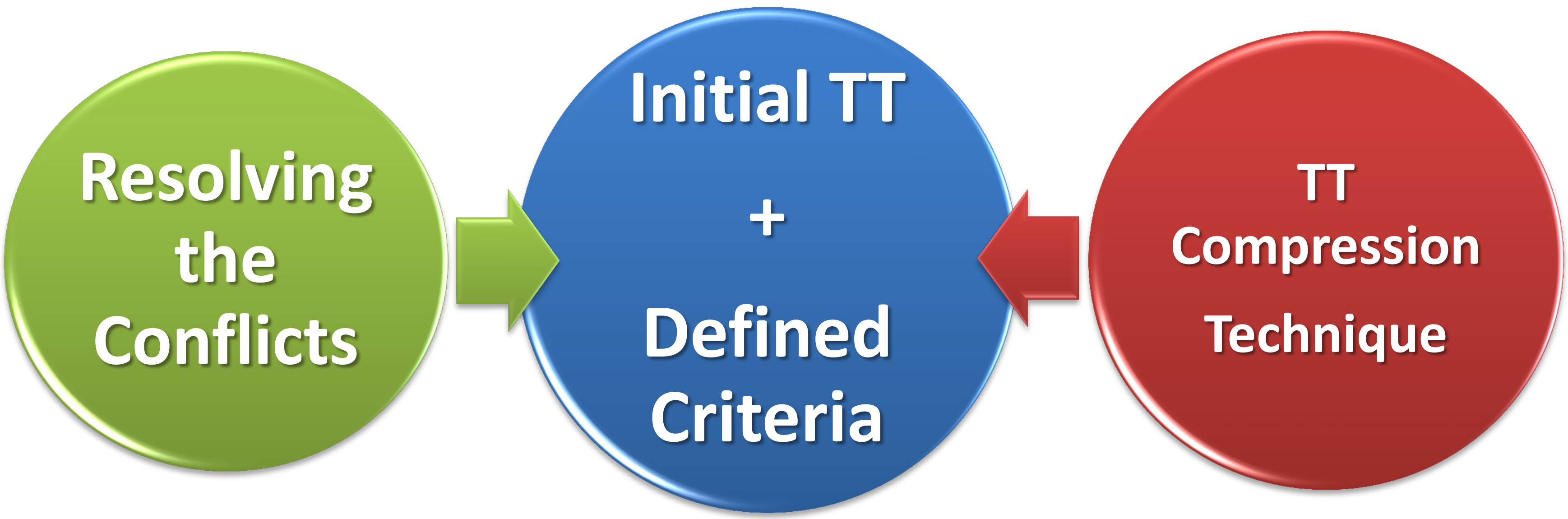
Battle between "TT Compression" & "Resolving Conflicts"



Key Parameters of HOTS Model

KEY Parameters:

- Initial departure times
- Flexibility of departure times
- Min/Max of dwell times
- Train-routes

HOTS Model, Objective Equation

$$\overbrace{}^{1}\quad\overbrace{}^{2}$$

$$MIN \quad \alpha_1 \times \sum_t \sum_i \underbrace{(XW_t^i - W_t^i)}_{1} \times R_t + \alpha_2 \times \sum_t \sum_i \underbrace{XDT_t^i}_{2} \times R_t$$

To minimize the deviation of dwell times (1) and departure times of trains (2), considering the importance weighting of dwell times and departure times

Model Constraints (Same-Order Approach)

$$XDT_t^i \geq DT_t^i - F1DT_t^i \qquad \forall t \in T \ , \forall i \in S \qquad \text{(EQ. 1)}$$

$$XDT_t^i \leq DT_t^i + F2DT_t^i \qquad \forall t \in T \ , \forall i \in S \qquad \text{(EQ. 2)}$$

(EQ. 1& 2) Departure times proposed by the model should be maintained between the earliest and latest possible departure time allowed for each train.

$$LW_t^i \leq XW_t^i \leq UW_t^i \qquad \forall t \in T \ , \forall i \in S \qquad \text{(EQ. 3)}$$

(EQ. 3) Dwell time proposed by the model should be maintained between the min and max dwell times allowed for each train.

Model Constraints (Same-Order Approach)

$$XDT_t^d - XDT_t^o = \sum_j \sum_i TR_t^{ij} + \sum_j XW_t^j \qquad \forall t \in T \;, \forall i, j \in S \;, \; |i - j| = 1 \;,$$
$$d \in D_t \,,\; o \in O_t \qquad \text{(EQ. 4)}$$

$$XDT_t^j = XDT_t^i + TR_t^{ij} + XW_t^j \qquad \forall\, t \in T \;, \forall\, i, j \in S \;, \; |i - j| = 1 \qquad \text{(EQ.5)}$$

(EQ. 4 & 5) guarantees that trains will not be lost in the model and each train follows the respective OD and routes, assigned in the model.

Model Constraints (Same-Order Approach)

$$XDT_t^i - XDT_p^i \geq H(T_p) + H(T_t) + (TR_p^{ij} - TR_t^{ij})$$

$$If\ (U_t \times U_p = 1)\ AND\ (DT_t^i > DT_p^i)\ AND\ (TR_p^{ij} \geq TR_t^{ij})\ AND\ (MR_p^{ij} = MR_t^{ij})$$

$$, \forall t, p \in T \quad , t \neq p \quad , \forall i, j \in S \quad , \quad |i - j| = 1 \qquad \text{(EQ. 6)}$$

$$XDT_t^i - XDT_p^i \geq H(T_p) \qquad If\ (U_t \times U_p = 1)\ AND\ (DT_t^i > DT_p^i)$$

$$AND\ (TR_p^{ij} < TR_t^{ij})\ AND\ (MR_p^{ij} = MR_t^{ij}) \quad \forall t, p \in T\ , t \neq p\ , \forall i, j \in S\ , \ |i - j| = 1 \qquad \text{(EQ. 7)}$$

(EQ. 6&7) These two constraints resolve any potential conflicts between each two individual trains in the **same direction**.

Model Constraints (Same-Order Approach)

$$XDT_t^i \geq XDT_p^j + TR_p^{ji} + H(T_p) \qquad If\,(U_t \times U_p = -1)\; AND\; (DT_t^i \geq DT_p^j)$$

$$AND\,(MR_p^{ji} = MR_t^{ij}), \quad \forall\, t, p \in T \;,\; t \neq p \;, \forall i, j \in S \;,\; |i - j| = 1$$

(EQ. 8)

(EQ. 8) Similar to Eq. 6 & 7, it resolves any potential conflicts between each two individual trains running in the **opposite directions**.

$$XDT_t^d - XDT_p^o \leq SH \qquad \forall\, t, p \in T \;,\; d \in D_t \,,\; o \in O_t$$

(EQ. 9)

(EQ. 9) The limitation of timetable duration.

$$XDT_t^i \geq 0 \;,\; XDT_t^i \in \text{integer} \;,\; XW_t^i \geq 0 \;,\; XW_t^i \in \text{integer}$$

(EQ. 10)

(EQ. 10) *Optimized departure times and suggested dwell times (variables) are positive integer values.*

Model Constraints ("Order-Free" Approach)

- In "Order-Free" approach, trains depart based on the earliest possible departure times, as determined based on allowed flexibility parameter (F1DT)
- Same objective and constraints similar to the **"Same-Order"** approach, except in:

$$XDT_t^i \geq XDT_p^i + H(T_p) + H(T_t) + (TR_p^{ij} - TR_t^{ij}) \quad If\ (U_t \times U_p = 1)\ AND\ (DT_t^i - F1DT_t^i > DT_p^i - F1DT_p^i)\ AND\ (TR_p^{ij} \geq TR_t^{ij})\ AND\ (MR_p^{ij} = MR_t^{ij}),\ \forall t, p \in T\ ,t \neq p\ ,\ \forall i, j \in S\ ,\ |i - j| = 1 \tag{6-a}$$

$$XDT_t^i \geq XDT_p^i + H(T_p) \quad If\ (U_t \times U_p = 1)\ AND\ (DT_t^i - F1DT_t^i > DT_p^i - F1DT_p^i)\ AND\ (TR_p^{ij} < TR_t^{ij})\ AND\ (MR_p^{ij} = MR_t^{ij})\quad \forall t, p \in T\ ,t \neq p\ ,\ \forall i, j \in S\ ,\ |i - j| = 1 \tag{7-a}$$

$$XDT_t^i \geq XDT_p^j + H(T_p) + TR_p^{ji} \quad If\ (U_t \times U_p = -1)\ AND\ (DT_t^i - F1DT_t^i \geq DT_p^j - F1DT_p^j)\ AND\ (MR_p^{ji} = MR_t^{ij}),\quad \forall t, p \in T\ ,\ t \neq p\ ,\forall i, j \in S\ ,\ |i - j| = 1$$

Testing the HOTS Model Applications

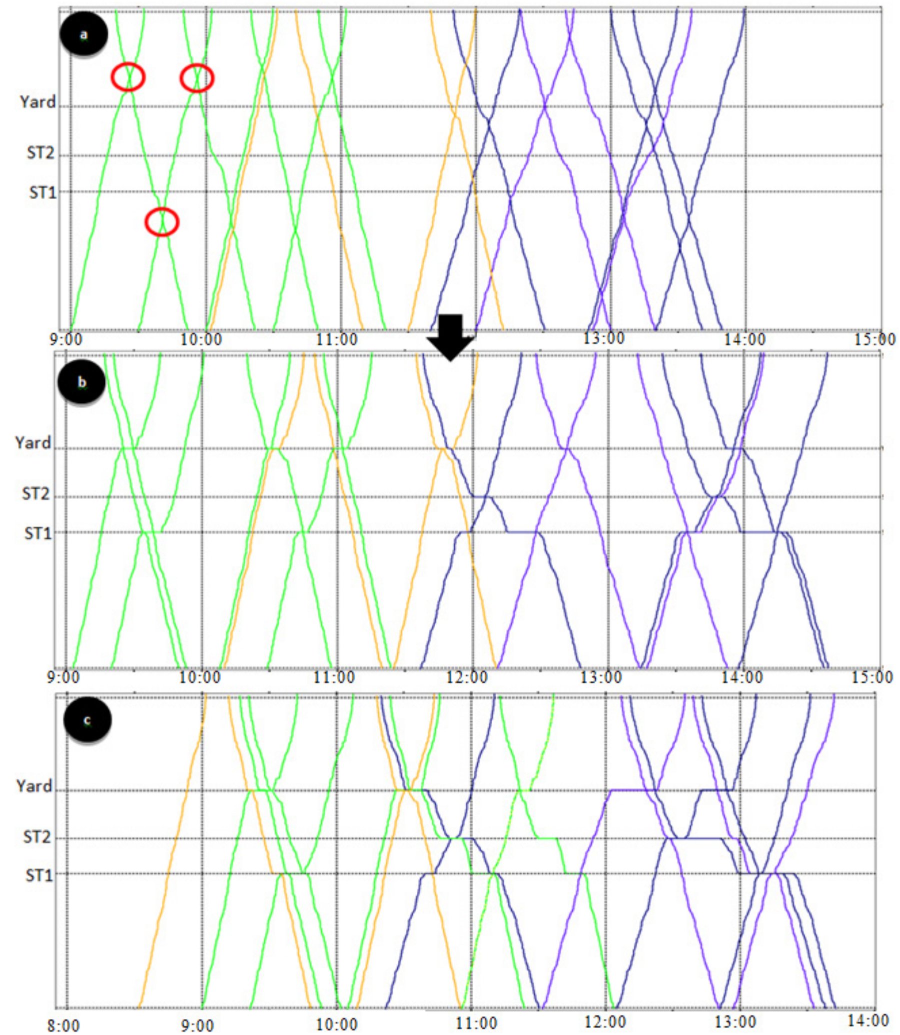
- **Different scenarios were applied on single and multiple track case studies to test the performance of the model:**
  - **Single Track Case Study**
    - 1-1- Improving an initial timetable with serious trains' conflict
    - 1-2- Improving an initial "Conflict-Free" timetable
    - 1-3- Comparing the compression techniques between RailSys and HOTS model (two scenarios)
  - **Double/Multiple-track Case Study**
    - 2-1- Timetable compression through rescheduling
    - 2-2- Rescheduling timetable based on rerouting a train

- **HOTS Model Operation**
  - LINGO 14 (solver)
  - MS Excel (dataset)
  - Case studies considered "stand-alone corridors"
  - Rescheduling/rerouting restrictions based on user input

HOTS Test 1-1 – Resolving Train Conflicts

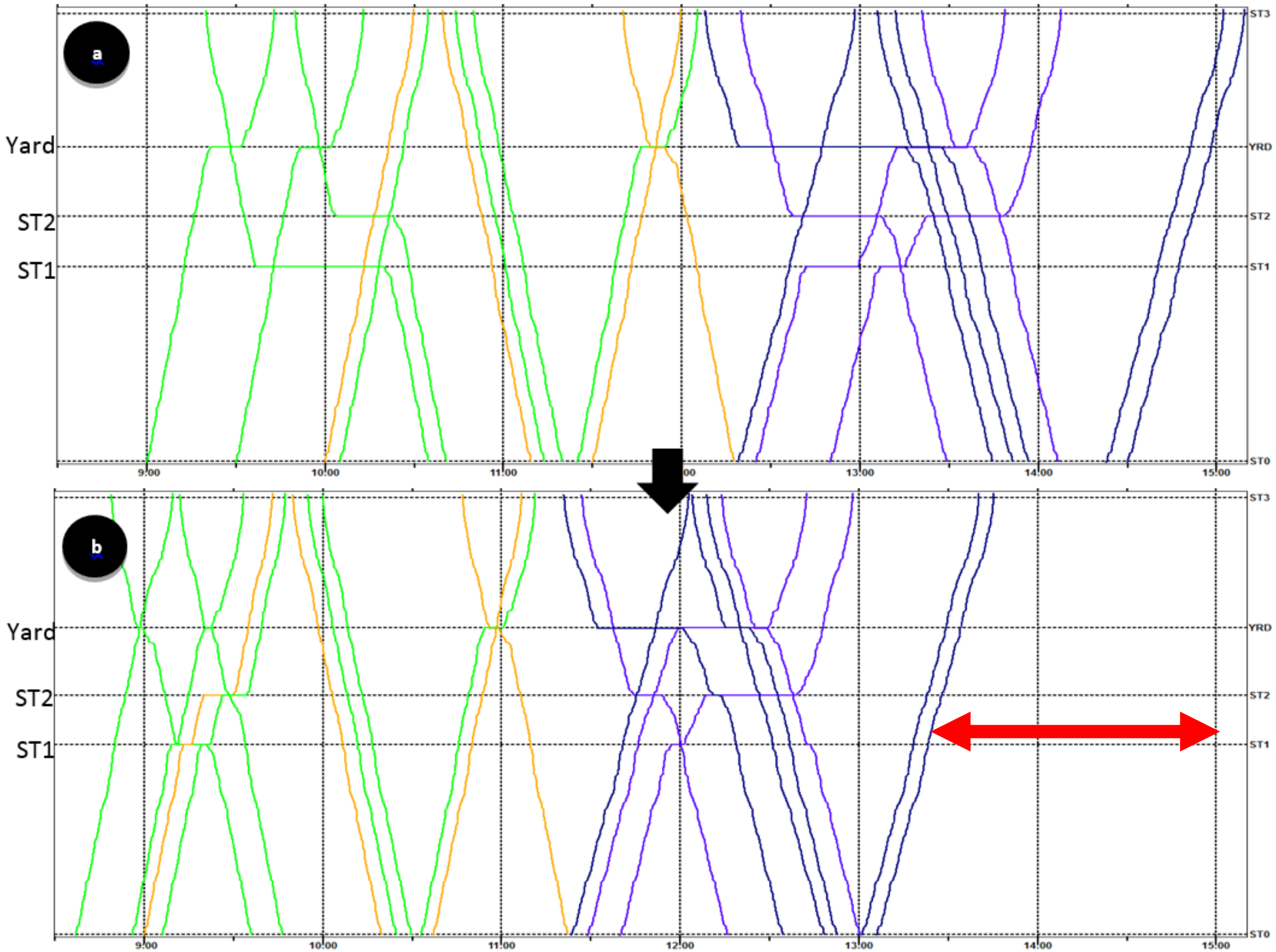
HOTS (Same-Order)

HOTS (Order-Free)



The initial timetable (a) with several schedule conflicts (three of them marked as example), improved timetables after the HOTS optimization, "Same-Order" (b) and "Order-Free" scenario (c)

HOTS Test 1-2 – Improving Timetable



HOTS

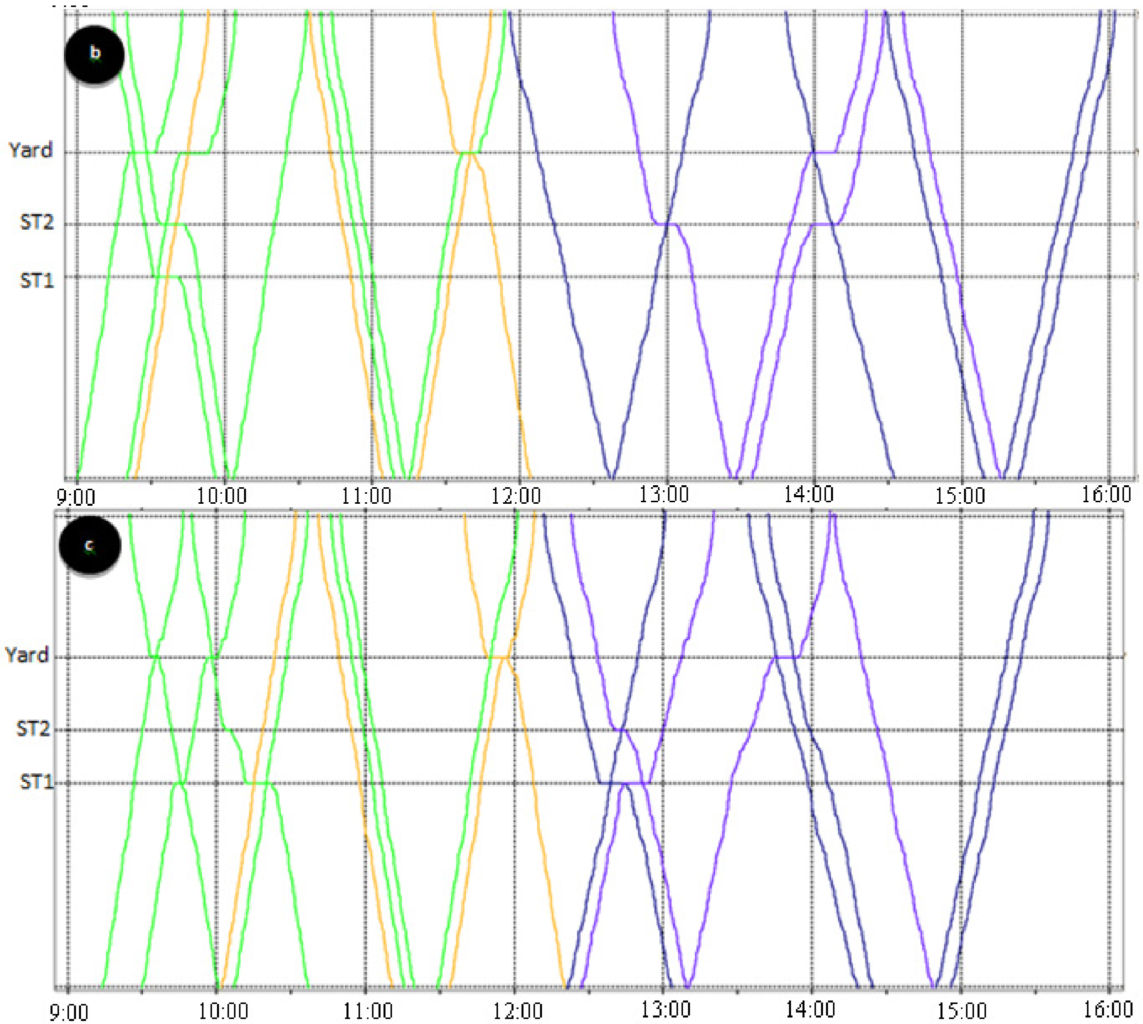
The initial timetable developed in RTC with no manual improvement (a) was improved using "Same-Order" approach of the HOTS model (b)

HOTS Test 1-3.1 – Comparative Compression

RailSys

vs.

HOTS



Comparison between a compressed timetable by RailSys (b), and the outputs by HOTS model (c) (Different compression techniques)

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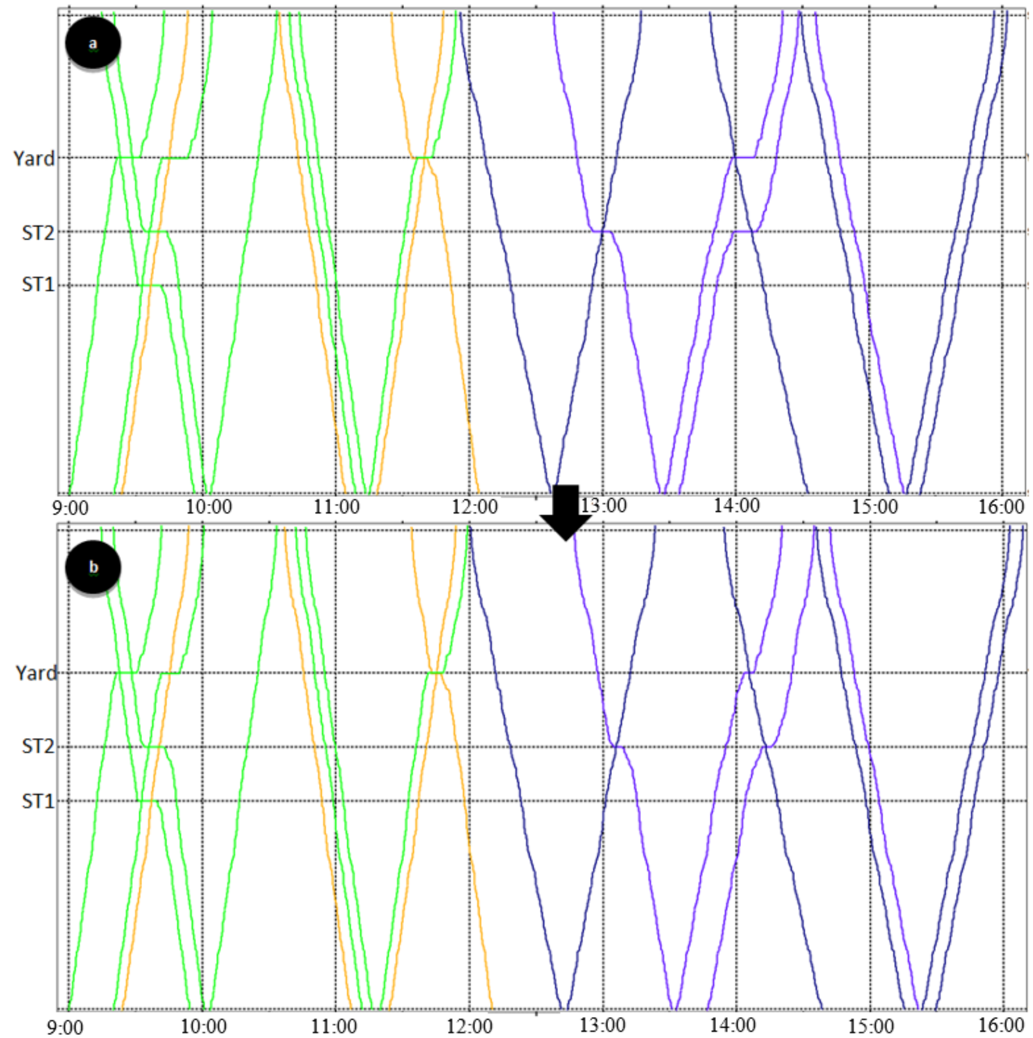
HOTS Test 1-3.2 – Further Compression

RailSys

HOTS



The already compressed timetable by RailSys, (a) tested for further improvement by HOTS model (b). (Equal outcomes)

Summary of HOTS Model Results (Single Track)

Criteria		Scenario 1-1		Scenario 1-2		Scenario 1-3	
		Initial TT*	Improved by HOTS	Initial TT*	Improved by HOTS	Improved by RailSys	Improved by HOTS
LOS	Number of stops	Several Conflicts	23	14	19	9	11
	Min. dwell time		0’	0’	0’	0’	0’
	Max. dwell time		20’	61’	30’	10’	10’
	Total dwell times		132’	271’	166’	80’	66’
Capacity	TT* duration		5h 30’	6h 10’	5h 25’	7h 04’	6h 28’
	TT* Compression (minutes / %)		-	-	45’	-	36’
			-	-	12%	-	8%

TT: Timetable*

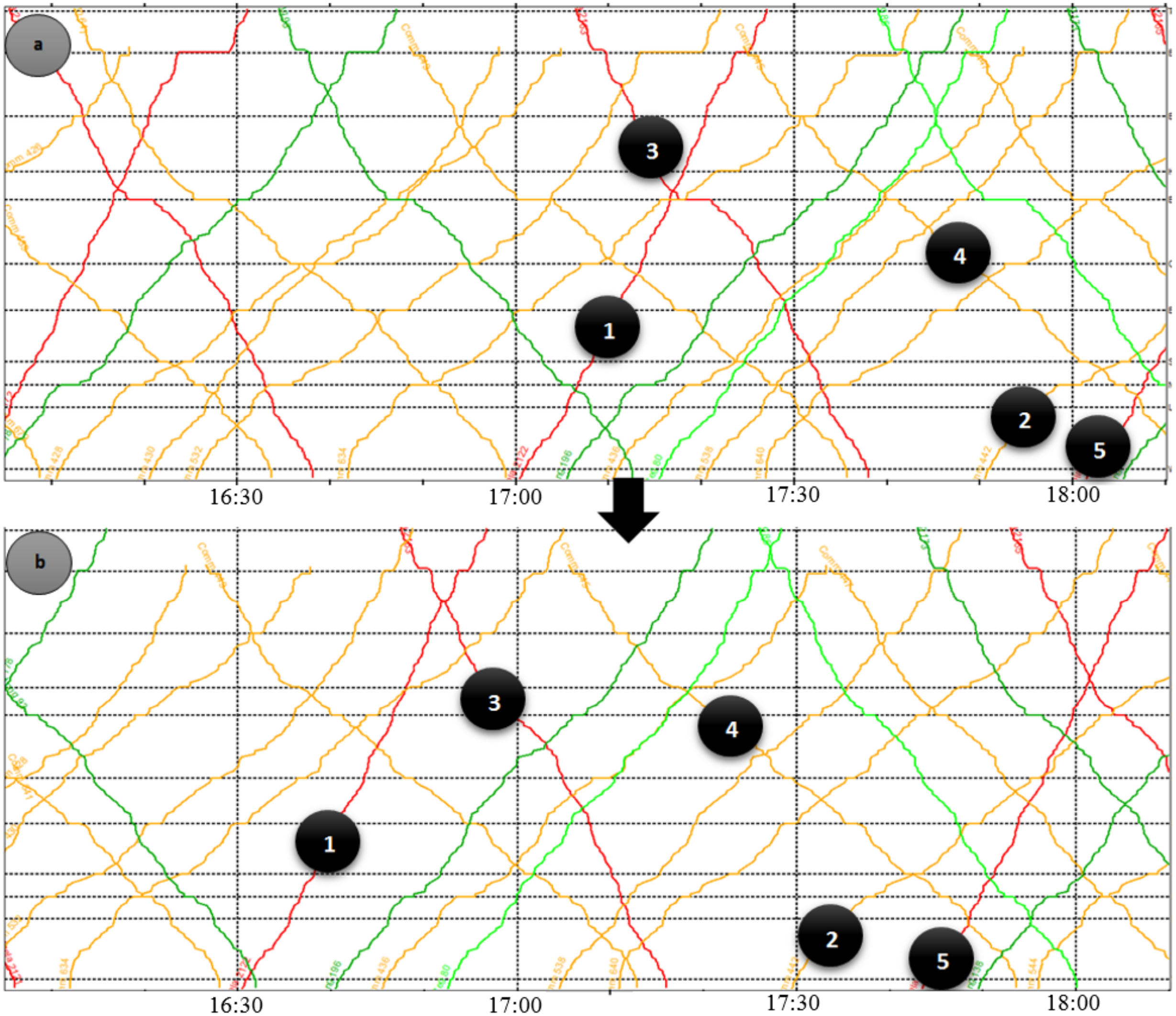
Conflicts Removed

Successful Compression

Comparative Compression (Different Compression Techniques)

HOTS Test 2-1 – Rescheduling Scenario

HOTS

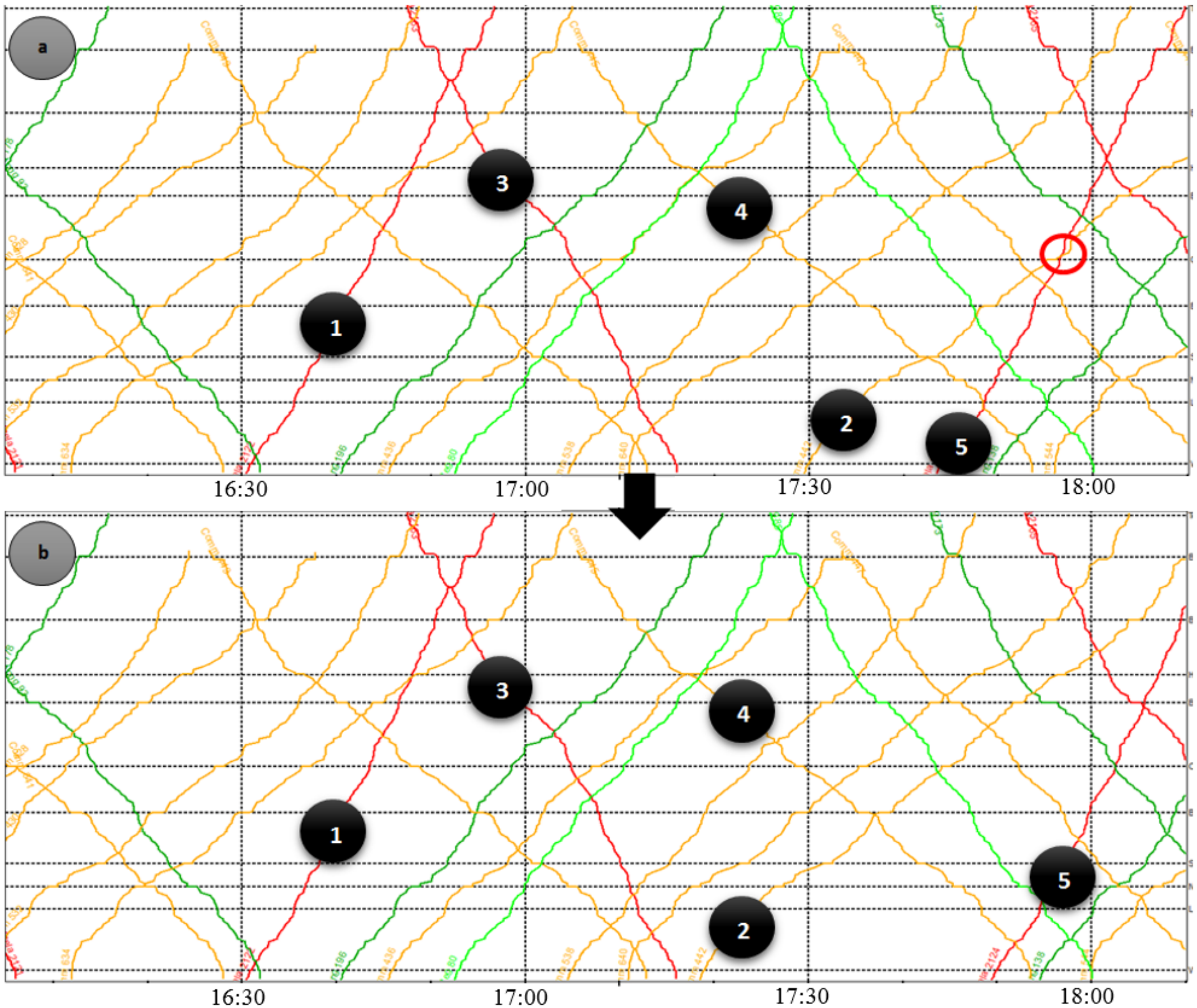


Initial (a) and rescheduled timetable (b) of a multiple-track corridor based on "Same-Order" approach of HOTS Model

HOTS Test 2-2 – Rerouting Scenario

HOTS

HOTS
After rerouting



Previous timetable developed in Scenario 2-1 (a) was rescheduled by the HOTS model to address the new route defined for Train #2 (b)

Summary of HOTS Model Results (Multiple Track)

Criteria		Initial TT*	Rescheduled by HOTS (Scen. 2-1)	Rescheduled by HOTS Based on New Route (Scen. 2-2)
LOS	Number of stops	402	402	402
	Min. dwell time	1’	1’	1’
	Max. dwell time	3’	2’	2’
	Total dwell times	557’	405’	405’
Capacity	TT* duration	23h 46’	22h 58’	22h 58’
	TT* Compression (Minutes, %)	-	48’	48’
		-	3.3%	3.3%

TT: Timetable*

Successful Compression

Maintained the same LOS and TT duration, while resolving the conflicts after rerouting

Investigating Trade-off Trends between Capacity and LOS

Four different initial timetable selected out of the same single track case study, (**same number of trains, same infrastructure**), but:

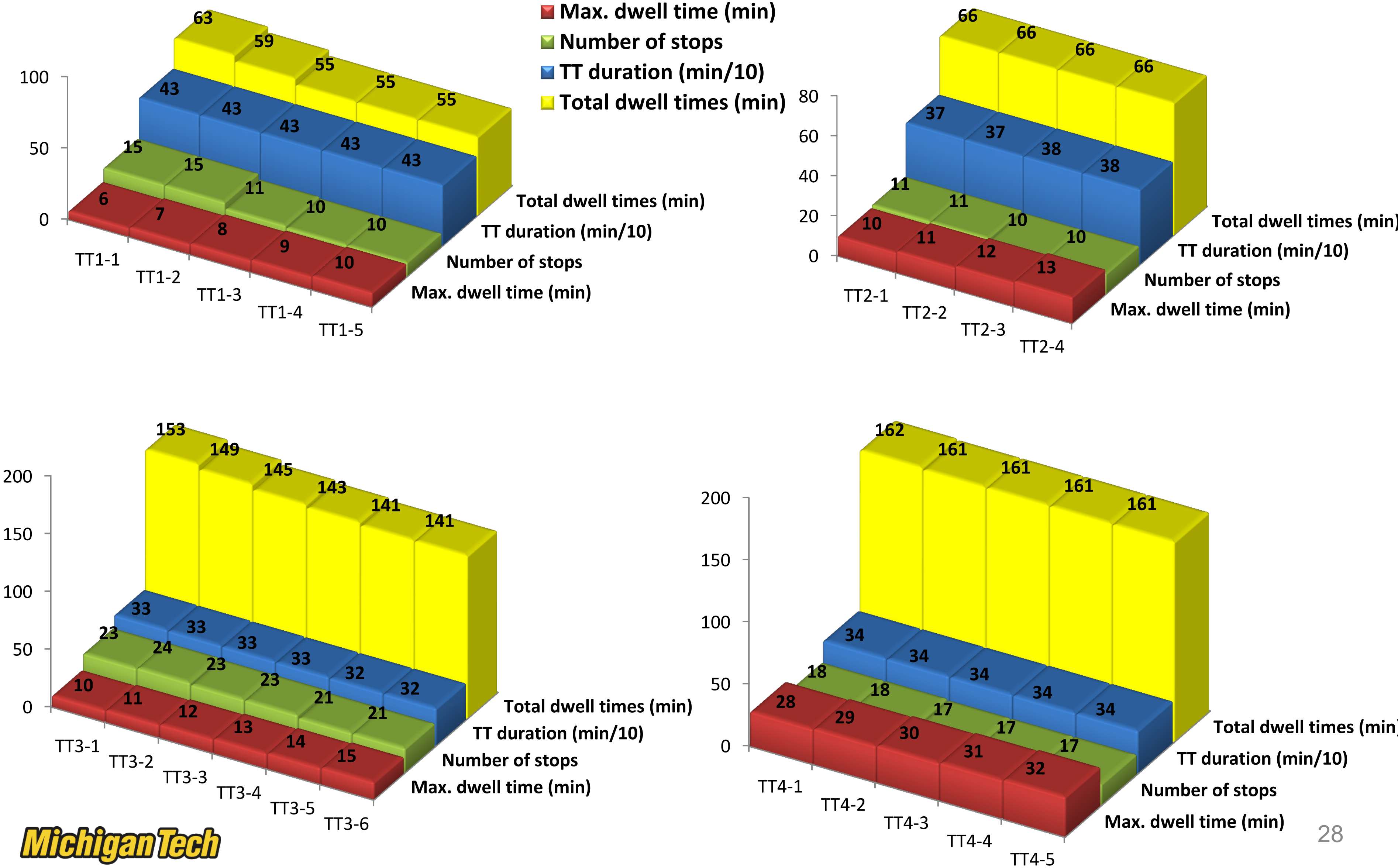
- **Different stop patterns**
- **Different initial departure times**

Criteria		Initial TT1	Initial TT2	Initial TT3	Initial TT4
LOS	Number of stops	9	0	0	14
	Max. dwell time	10’	0’	0’	61’
	Total dwell times	80’	0’	0’	271’
Capacity	TT* duration	7h 04’	6h 10’	5h 00’	6h 10’

TT: Timetable*

	Initial TT1	Initial TT2	Initial TT3	Initial TT4
	Conflict-free Good LOS	Conflict Congested	Conflict Over Congested	Conflict-free Congested

Investigating Trade-off Trends between Capacity and LOS



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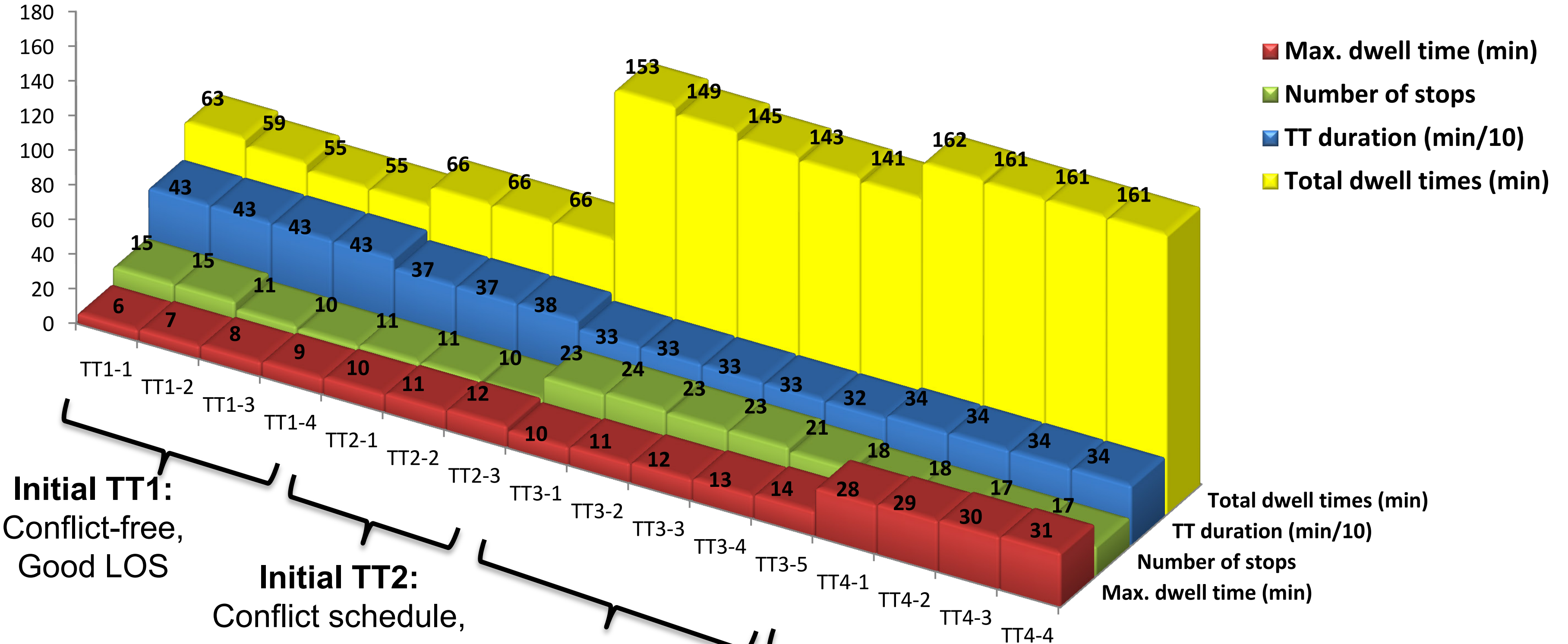
Investigating Trade-off Trends between Capacity and LOS



Initial TT1:
Conflict-free,
Good LOS

Initial TT2:
Conflict schedule,

Initial TT3:
Conflict schedule
Over Congested

Initial TT4:
Conflict-free,
Congested

Overall, Reverse Correlation between “Capacity Utilization and LOS”

Type of “Initial Timetable” is a key element.

Summary and Conclusions

- Different methodologies should be investigated/considered to address rail capacity issues
- Operational management methodologies provide an alternative when capital improvements not possible
  - Timetable compression shows potential for increased corridor utilization
  - Reduction of recovery time during unexpected events/delays is one drawback
- A new standalone model called **"Hybrid Optimization of Train Schedule" (HOTS)**. Key highlights:
  - Analytical model to supplement commercial rail simulation
  - Applicable on various types of rail networks
  - Different parameters of rescheduling/compression techniques
  - Rescheduling /rerouting scenarios (Conflict-free)
  - Rescheduling under "Same-Order" or "Order-Free" approaches

HOTS Model Testing and Recommendations

- **HOTS Model** was successfully tested on different scenarios:
  - Conflict resolution
  - Improving and compressing the initial timetable
  - Despite differences in technique, similar compression results with RailSys
  - Demonstrated the trade-off between capacity utilization and LOS parameters on a single track case study
- Updates to remove/reduce current limitations:
  - **Station capacity limits**
    - New constraint
    - Update the station concept from “Node-based” to Link-based” pattern
  - **TT Compression to the right side** (concept of departing some trains “Later” instead of “Early” departure)
  - **More user-friendly interface/solver**
  - Model with **“Stochastic”** technique instead of **“Deterministic”** approach (freight trains)
  - **New applications:**
    - Public transit (subway, LRT, Commuter services)
    - Real-time rescheduling/rerouting application

Thanks for Your Attention!

Question or Comment?

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Acknowledgment:

Amtrak (Davis Dure)

Berkeley Simulation-RTC (Eric Wilson)

Lindo Systems, INC.- LINGO (Mark Wiley)

OpenTrack (Daniel Huerlimann)

RMCon GmbH- RailSys (Sonja Perkuhn, Gabriele Löber)

Michigan Tech. University (Jack Kleiber)

This research was supported by National University Rail (NURail) Center, a US DOT-OST Tier 1 University Transportation Center

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