The Intelligent Machinery Behind Airline Ground Ops

Claude Philippe Medard, Nidhi Sawhney
SAP

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Global Center of Excellence
SAP BTP

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Agenda

- SAP BTP (Extension & Innovation Platform)
- Overview of Ground Ops sub-processes (excluding ATC, Taxi in/out routes, runway ops)
- Two Problems (and then some)
  - Stand & Tow Planning
    - Stand & Tow Recovery
    - Baggage Planning
  - Turn Around Operations Scheduling & Target Off-Block Time (TOBT) Prediction
- Time Frame : 9 months hitting 42 dnata systems, Ops Systems, …

SAP BTP is the platform for Customers and Partners

Many of our Customers & Partners need to extend AI/ML capabilities with Decision Optimization for Actionable AI both in Planning and Execution

SAP provides decision optimization capabilities but only in embedded form in standard products

SAP BTP Cloud Services

Enterprise readiness with holistic lifecycle management

- ➔ Change and deployment management
- ➔ Technical ops automation
- ➔ Alerting
- ➔ Smooth integration option into existing ALM processes

Business Technology Platform

Discovery Center

Actionable & guided missions | Service catalog | Best practice enablement & learning content

Ecosystem and Marketplace

Integration packs | Pre-built industry & LoB content | Business workflows & bots | Business apps- & third-party data

App Dev	Automation	Integration	Data and Analytics	AI
➔ SAP Build Apps ➔ SAP Build Work Zone ➔ SAP Business Application Studio • Mobile Services • Runtimes (Cloud Foundry, Kyma) • Document Management Services ➔ SAP BTP ABAP Environment	➔ SAP Build Process Automation • Workflow Management • Decisions & Rules • RPA bots • Process Visibility ➔ SAP Task Center	➔ SAP API Business Hub ➔ SAP Integration Suite • Cloud Integration • API Management • Trading Partner Management • Integration Advisor • Open Connectors • Event Mesh • Integration Assessment ➔ SAP Master Data Integration ➔ SAP Advanced Event Mesh	➔ SAP Analytics Cloud • Business Intelligence • Augmented Analytics • Enterprise Planning ➔ SAP Data Warehouse Cloud ➔ SAP Data Intelligence Cloud ➔ SAP Master Data Governance ➔ SAP HANA Cloud	➔ SAP AI Business Services • Business Entity Recognition • Data Attribute Recommendation • Document Classification • Document Information Extraction • Service Ticket Intelligence • Personalized Recommendation ➔ SAP AI Core & SAP AI Launchpad

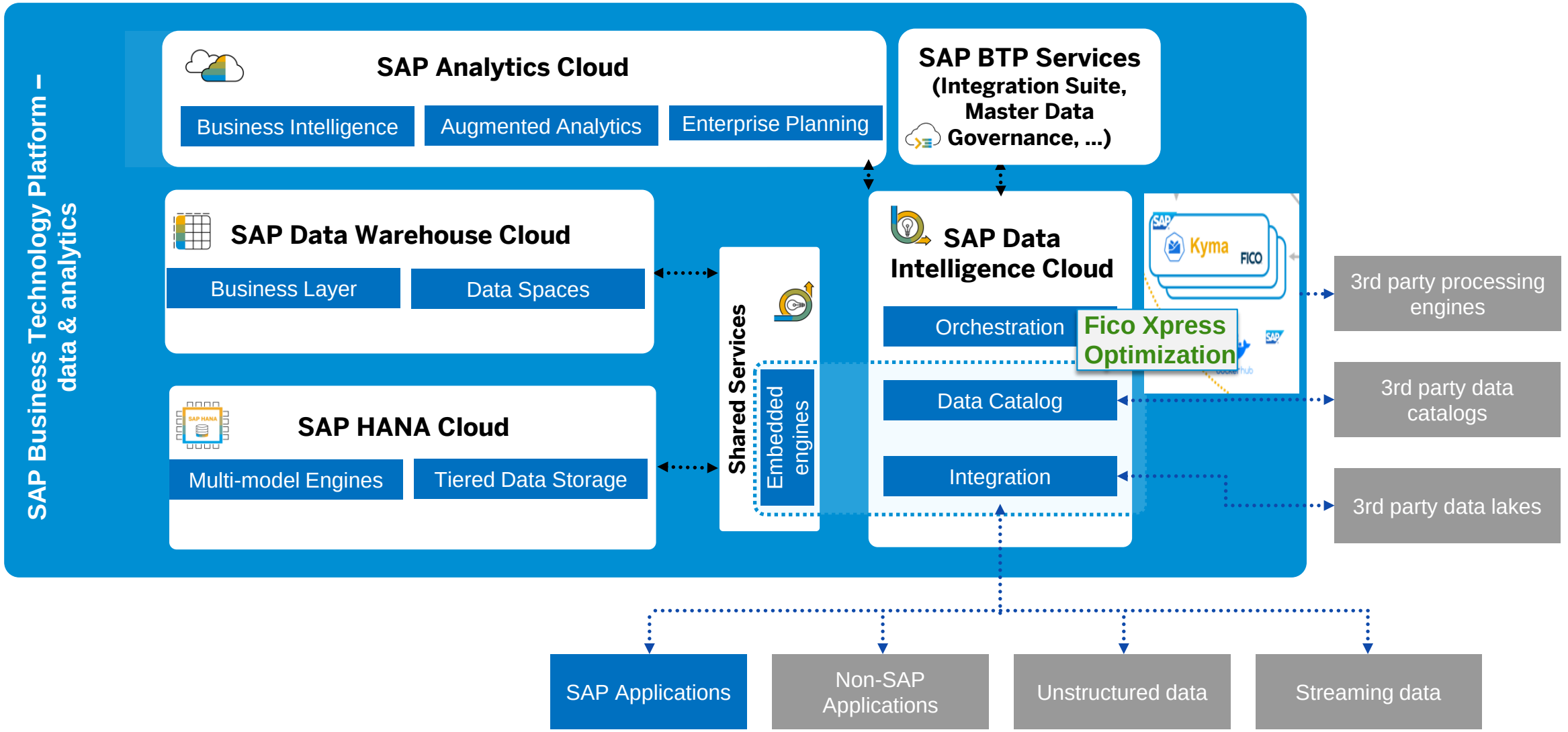
Enterprise security services and hybrid identity & access management

- ➔ Cloud identity services
- ➔ Risk & compliance
- ➔ Secure development

SAP BTP data & analytics solutions

Enabling an end-to-end data/AI/ML/Optimization fabric to drive business outcomes

SAP BTP



SAP Data Intelligence – Core Capabilities

Data Integration

Connect and **integrate everything**, structured, unstructured or streaming

Amazon Redshift · Google Cloud Platform · amazon web services S3 · hadoop · Microsoft Azure · SAP

Data Processing

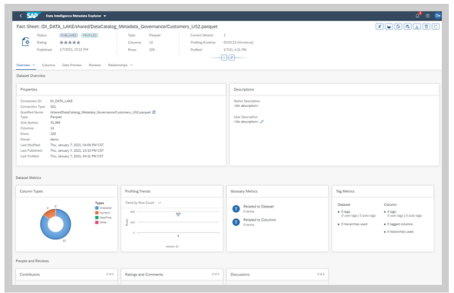
Extract meaning from data, orchestrating any mix of engines

python · R · TensorFlow · GO · Apache Spark · node.js · JavaScript · SAP

Fico Xpress Optimization

Data Catalog

Discover, classify, profile, understand and **prepare** all your enterprise data assets



SAP Data Intelligence – Data Integration

Data pipelines integrate disparate data across distributed infrastructures

Structured Data

Unstructured Data

Streaming Data

SAP ABAP

SAP IQ

SAP BW

SAP IoT

SAP DWC

SAP HANA & HANA Cloud

SAP Open Connectors

SAP IoT

SAP Enterprise Messaging

Microsoft SQL Server

IBM DB2

OPENAPI INITIATIVE

ORACLE

MuSQL

Microsoft SQL Azure

amazon REDSHIFT

ODBC

Alibaba Cloud

Amazon Redshift

amazon web services S3

Google Cloud Platform

hadoop

Google BigQuery

Microsoft Azure

NATS

kafka

WAMP

Google Cloud Pub/Sub

MQTT.ORG

Custom: Bring Your Own Connectivity

Note: this slide represents only a non-exhaustive subset of the systems accessible via Data Intelligence

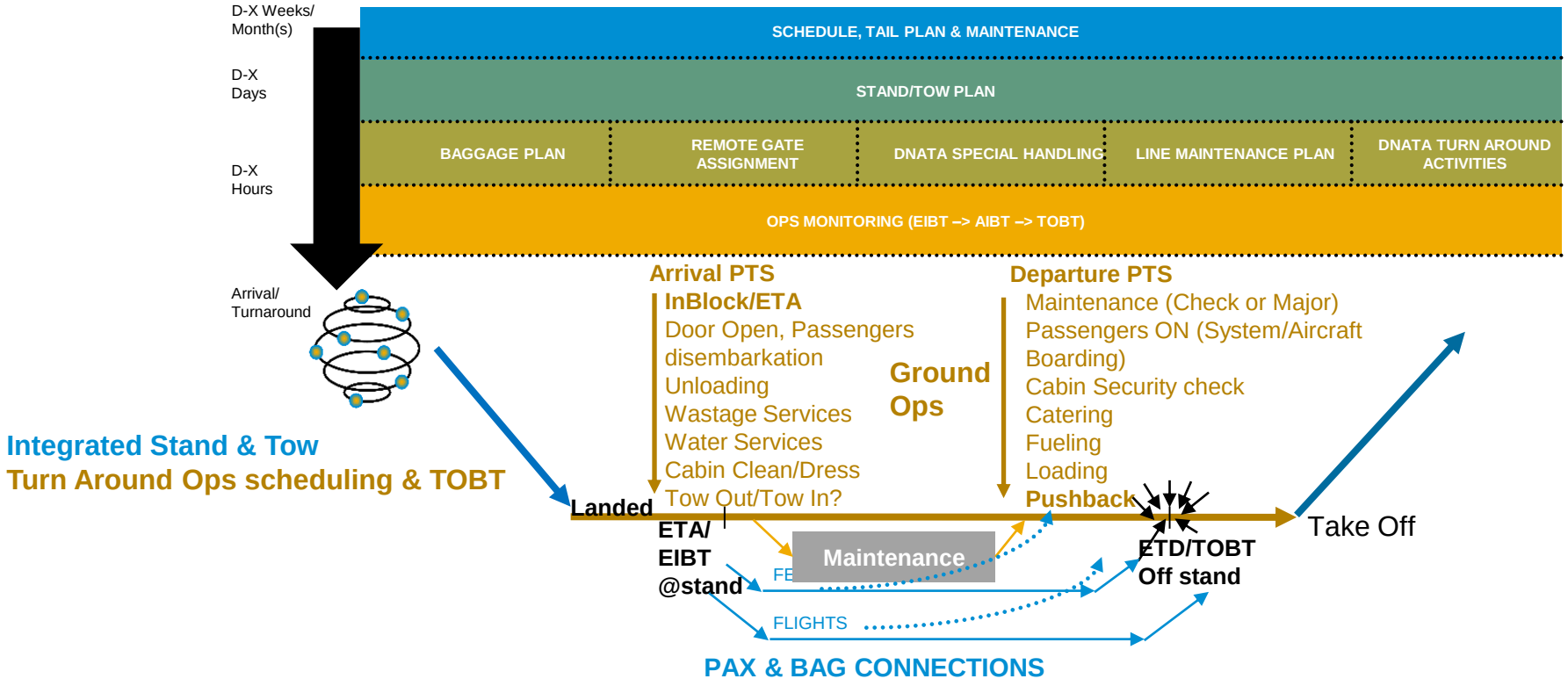
Overview

Integrated Hub Control
Ground Operations

Key Airline Group priorities:

- Increase OTP while ensuring passenger satisfaction through embedding intelligence in Ground Operations
- Understanding how to mitigate against disruption events and their knock on effects both at HUB and Network

Airline Group and SAP have co-innovated to deliver several components of Integrated Hub Control like Stand & Tow Solution, Ops Monitoring TOBT, and Baggage Handling Optimization



OTP requires **optimal** Stand and Tow Planning, **optimal** Baggage Planning, and **on time Turnaround Ops scheduling** for aircraft during the **day of Operations,** where **Target Off block time (TOBT)** secures the required take-off slot from ATC.

Stand & Tow Planning to Recovery

Business Challenges

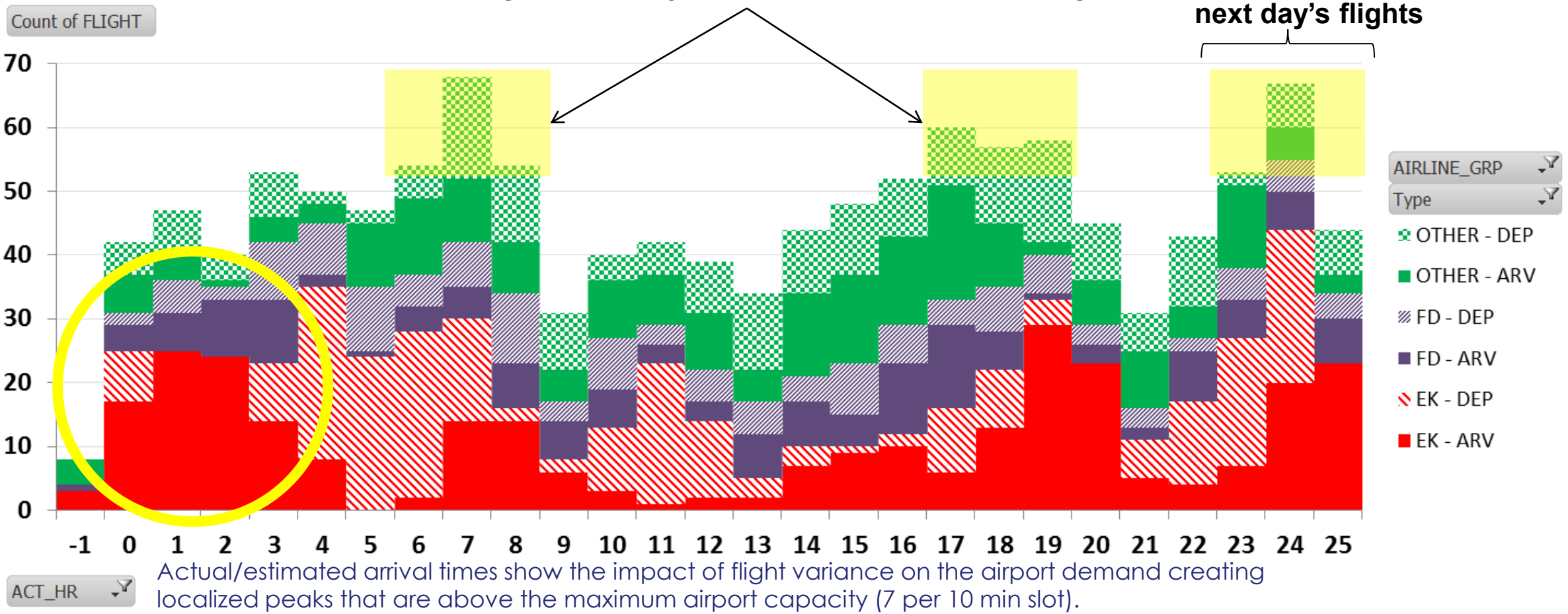
- Aircraft compliance with maintenance schedules
- Towing traffic compliance and high cost of aircraft towed
- On time performance considering passenger and bags connections
- Complex planning and recovery rules on the day of operations
- Automatic recovery plans
- Decision Time Reduction during the day of operations
- Allow Tail Swaps for Departing Flights…(common last resort strategy/trick…)

The Tow Problem

A Typical Day at DXB – Actual Traffic Flow

Example of a localized, unexpected traffic peaks resulting from flight variability which leads to arrival holding

23 Flights shift into next day creating unexpected peak with next day's flights



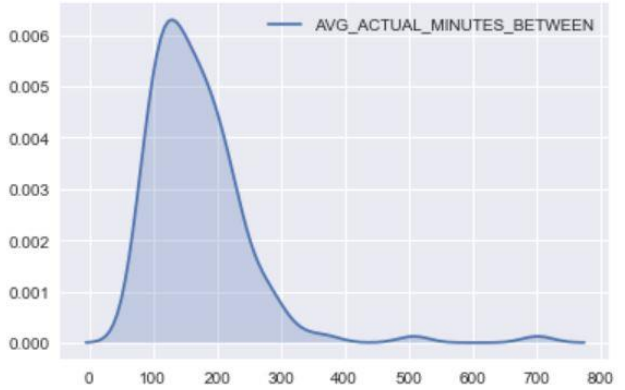
Actual/estimated arrival times show the impact of flight variance on the airport demand creating localized peaks that are above the maximum airport capacity (7 per 10 min slot).

In particular, flights arriving during the period from 5-7 UTC and 0-1 UTC the next day would be expected to experience some airborne arrival holding

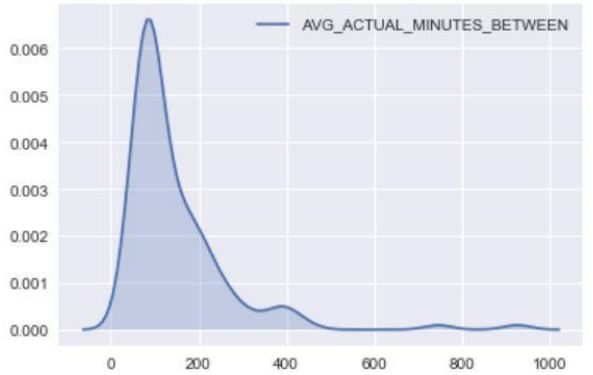
Tow planning goal

- Well planned start and end times to tows
- Tows planned in alignment with the flow rate of the airport by Zone

Actual Tow-In Distribution



Actual Tow-Out Distribution

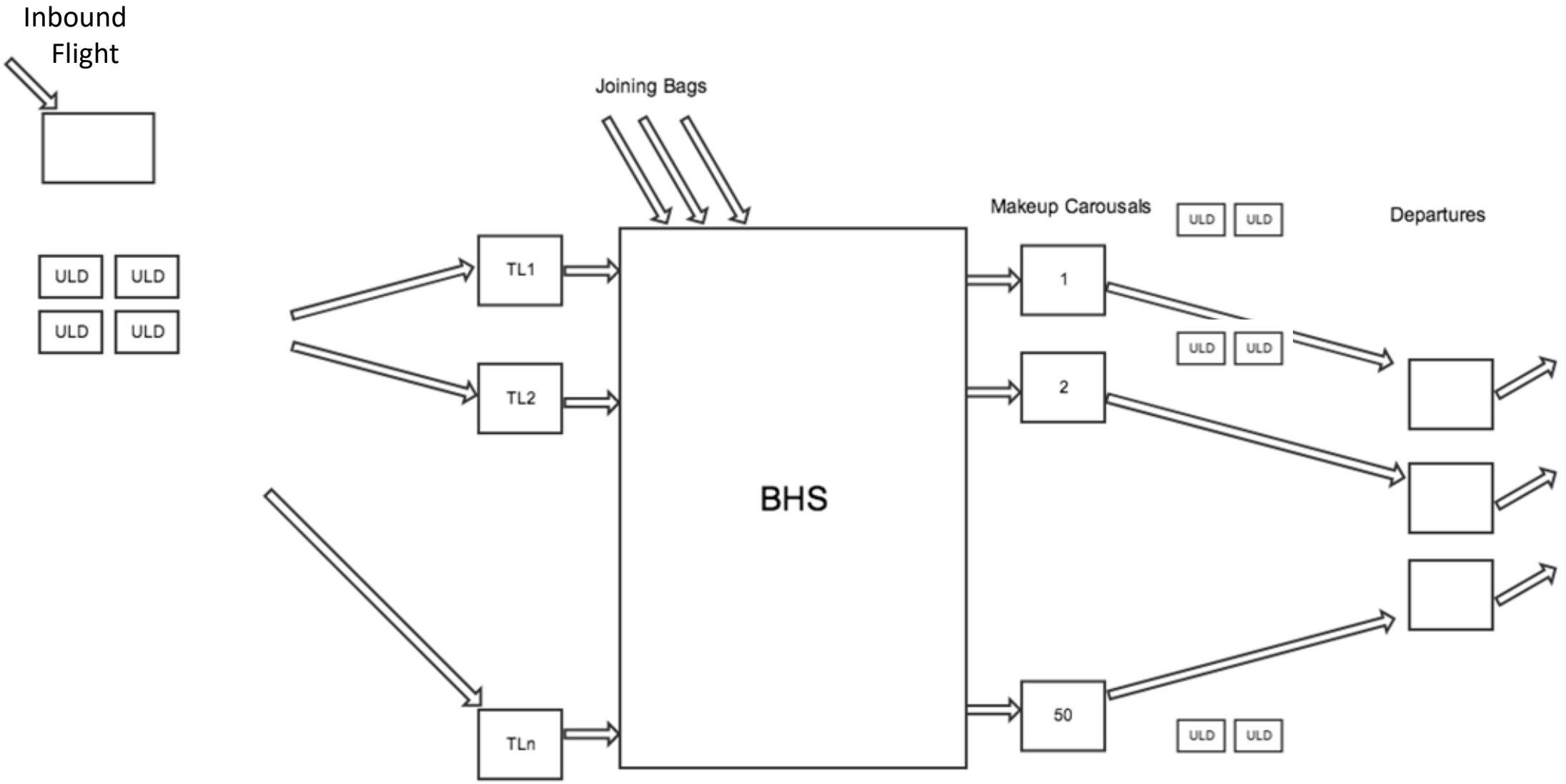


Optimization Enhancements

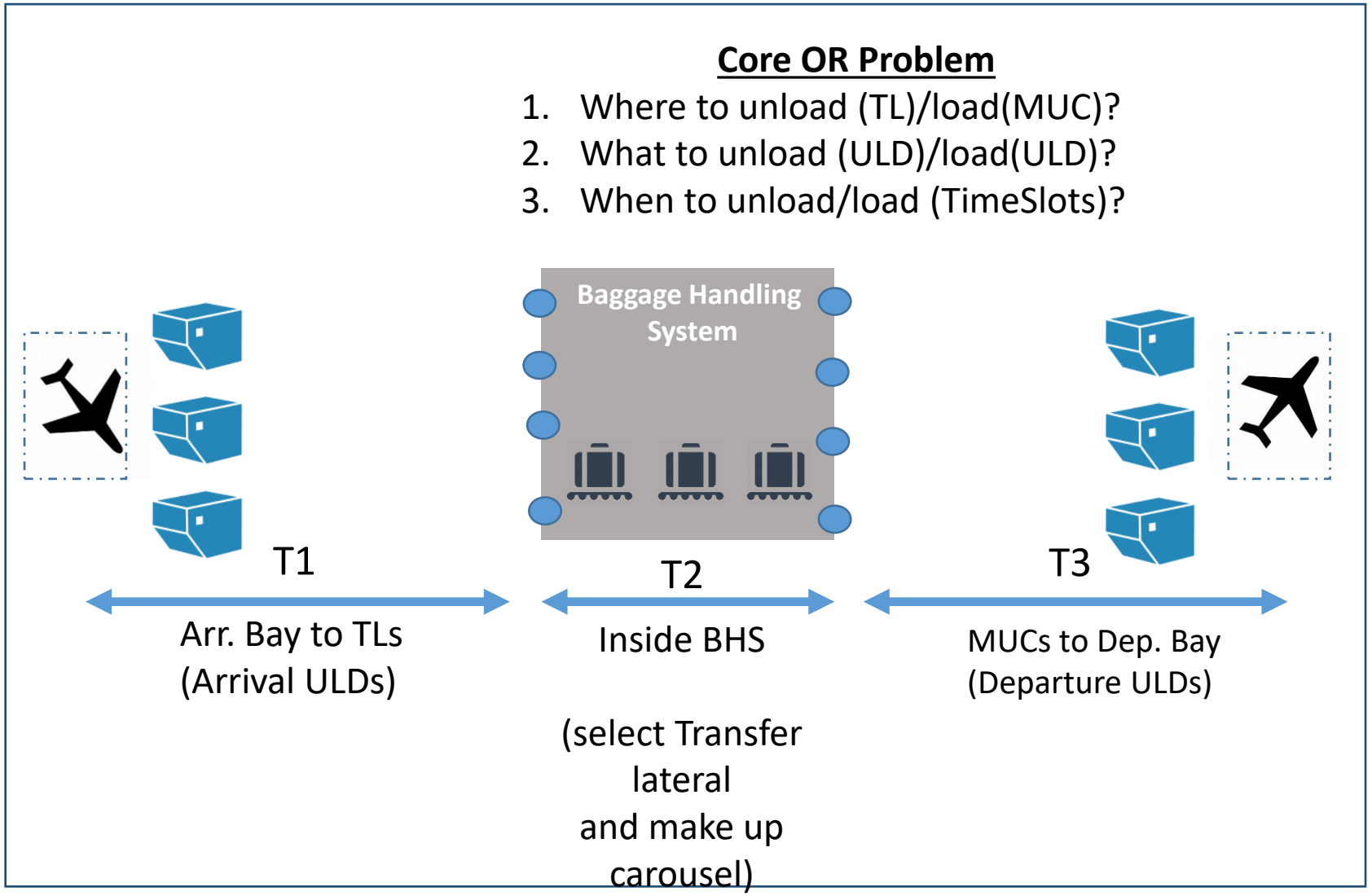
- More specific time constraints on when to start and end-tows and ensure their feasibility
- Optimal tows for better tail placement and not necessarily tow reduction

Baggage Transfer Planning

Optimization Problem : Baggage Transfer Planning

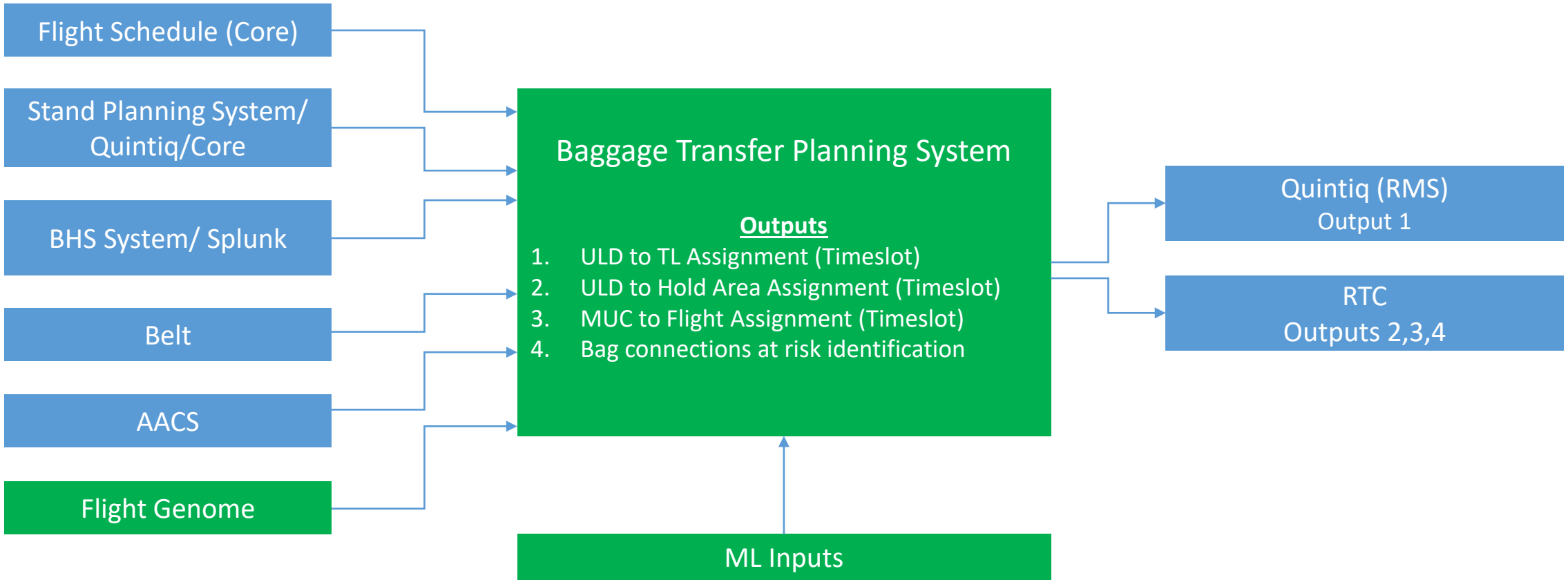


require a baggage planning OR to optimize the transfers



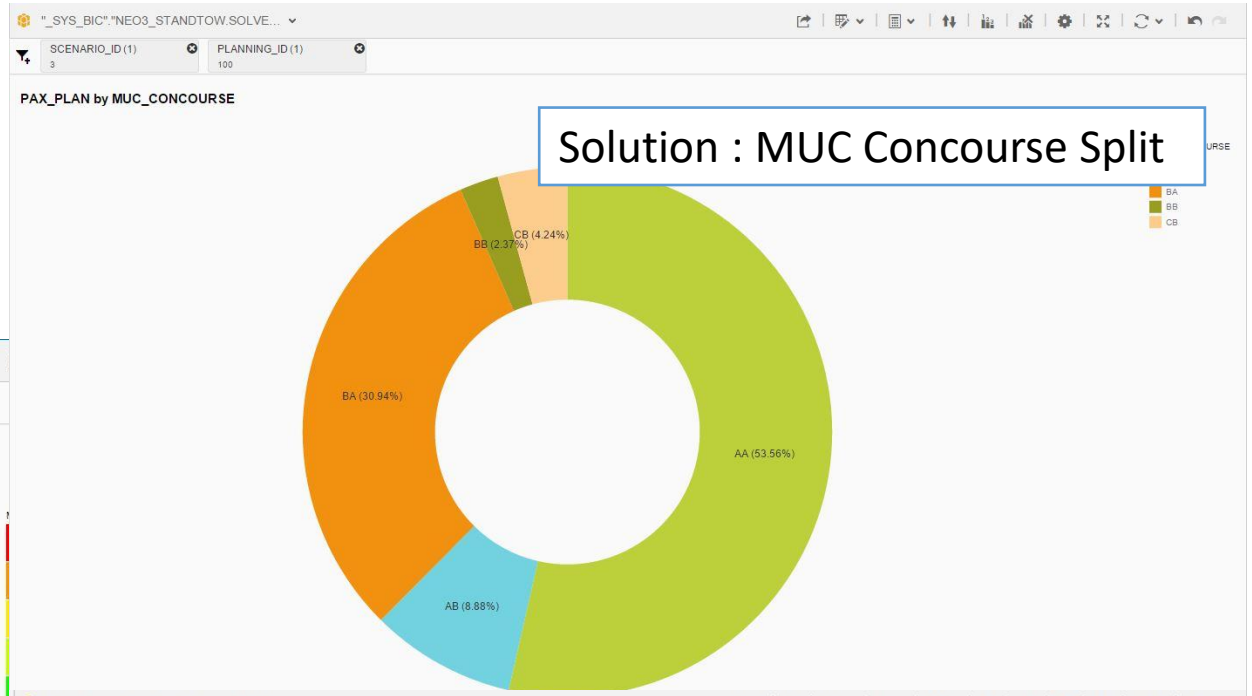
Optimizer High Level Details	
Obj Fx	• Schedule compliance • Minimize Bags misc
Rules	• Security Rules • Min duration for ground time, tow etc • Other business soft rules
Inputs	• Dynamic Inputs (Schedule, Connections etc) • Fixed Inputs (baggage capacity) • ML Inputs (EIBT, # baggage volume)
Output	• Baggage Transfer Plan (Transfer lateral and Make up carousal plan)

Baggage Transfer Planning System Solution Architecture

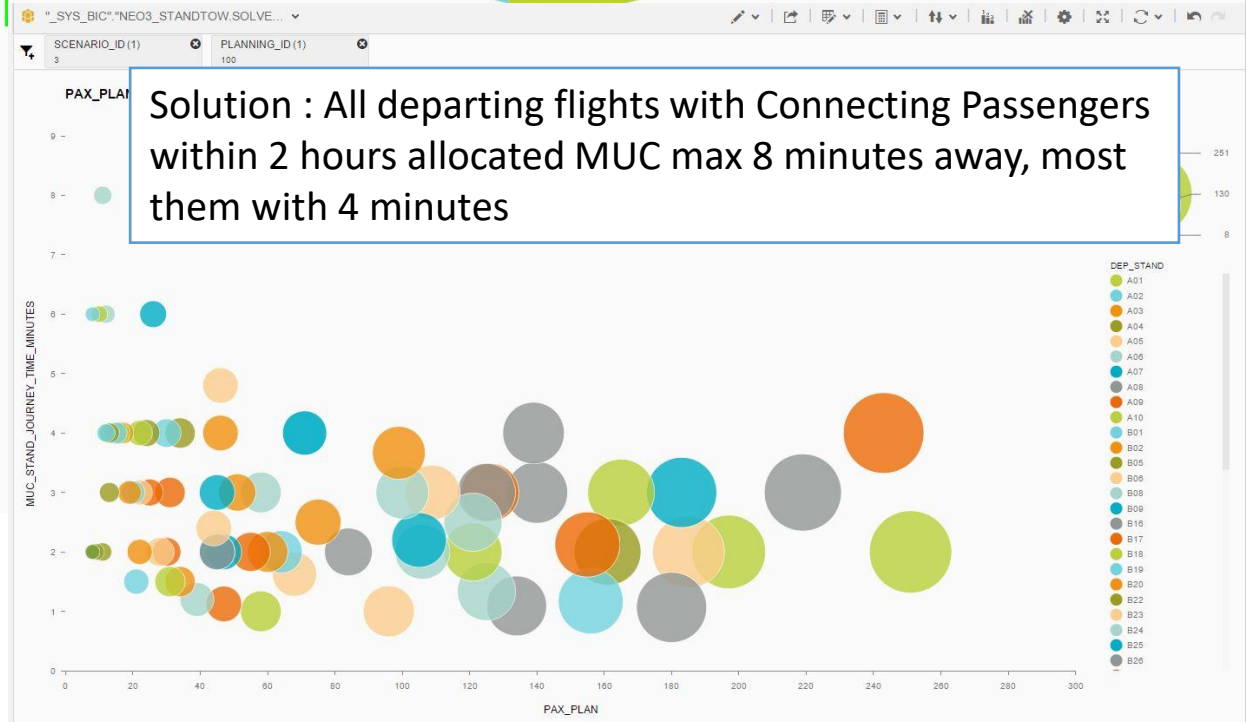


MUC Allocation

Input: MUC_TO_STAND_JOURNEY
(Above using 60% Chance)



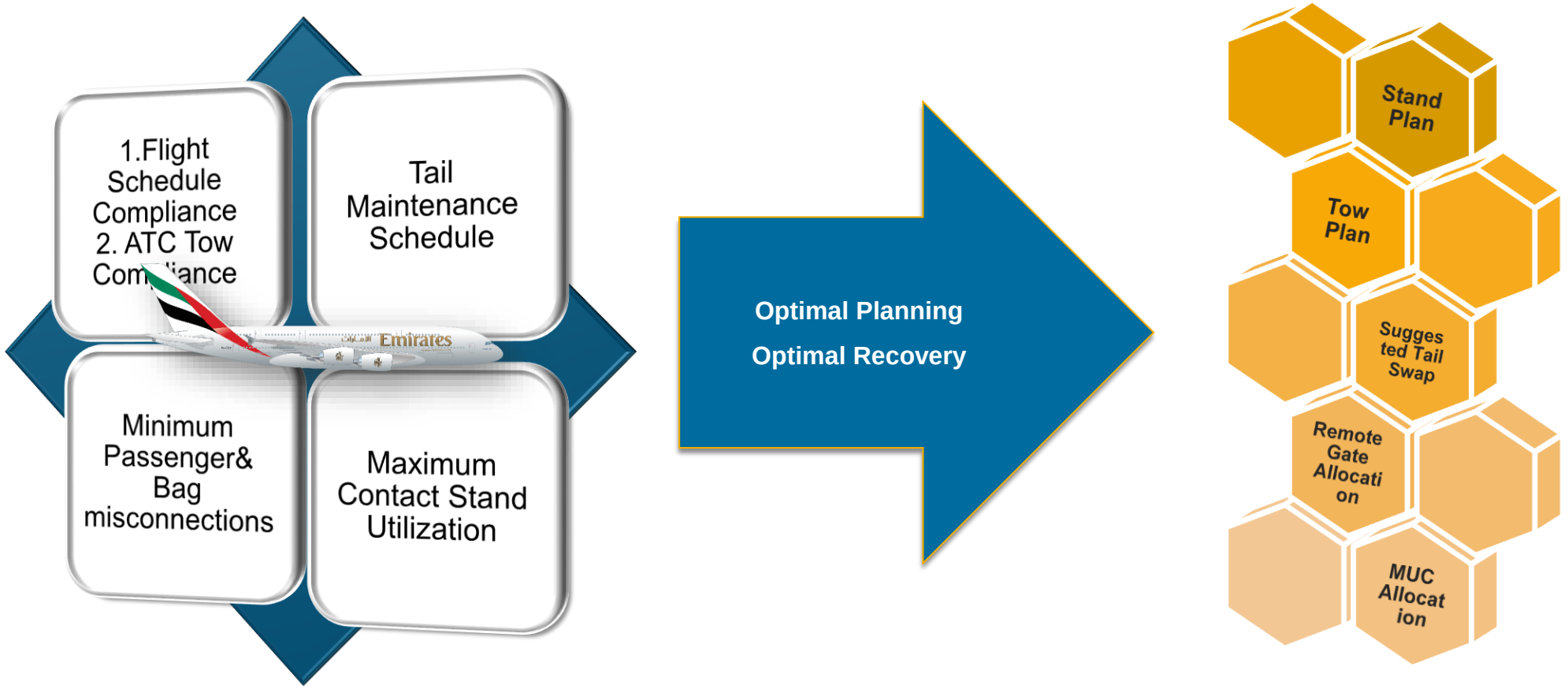
Solution : MUC Concourse Split



Solution : All departing flights with Connecting Passengers within 2 hours allocated MUC max 8 minutes away, most them with 4 minutes

Optimization Challenge

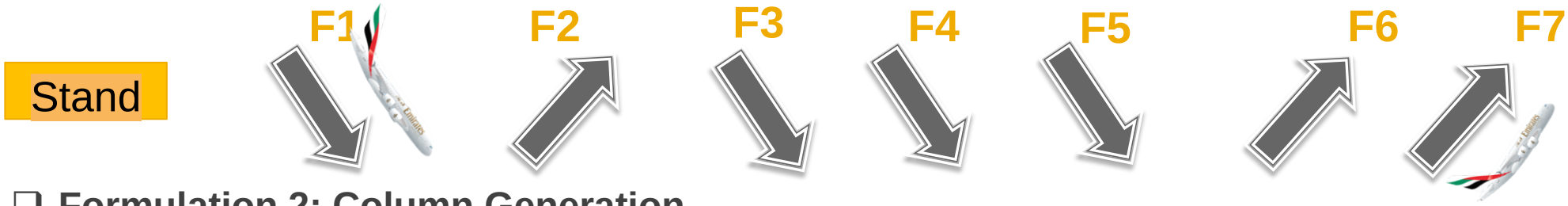
Make Passengers, Airport Control, Maintenance, Baggage Ground Crew all Happy at the same time



Two Points of View of same problem: complementary mathematical formulations

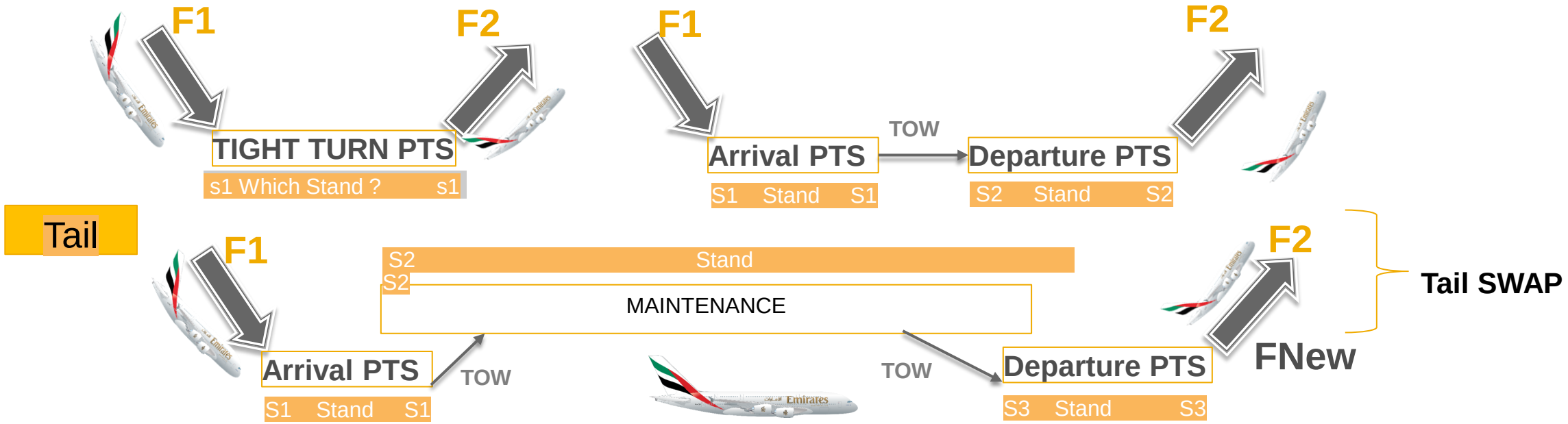
❑ Formulation 1 : Generalized Assignment & Scheduling Problem (GASP) Flight-Tail Assignment unchanged

Stand Point of View (sequence of flights being processed)



❑ Formulation 2: Column Generation

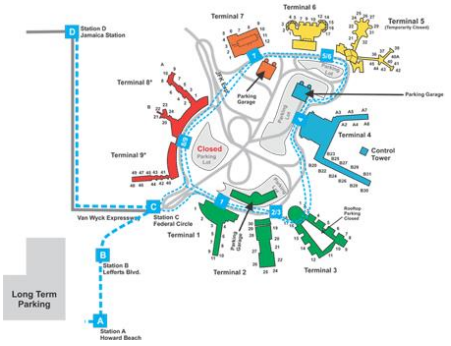
Tail Turn Point of View (necessary for Tail Swap requirement)



Data sources & flows

Facts

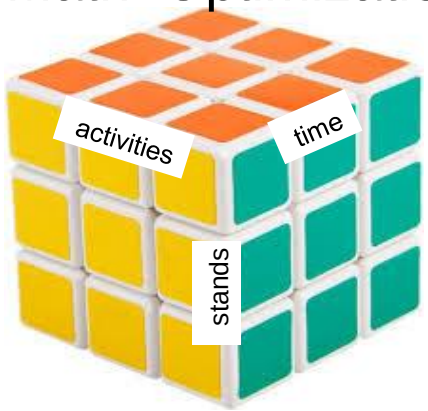
Tail Schedule
Flights and Maintenance activities assigned to planes



Airport Layout
Terminals, Concourses, Stands, Gates.
Relationship of stands to runways, security gates, capacity of remote gates
Distance between stands for PAX, for Tail Availability / Maintenance of stands

PAX data
PAX transfers, Flight occupancy, SPHL PAX, Baggage amount

Math. Optimization

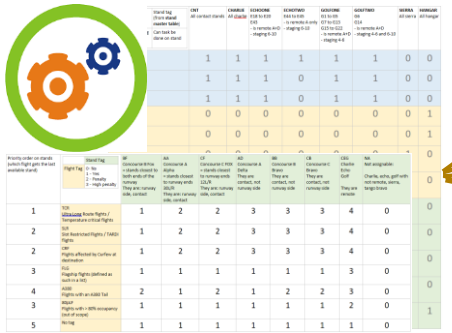


minimum costScore

Stand & TOW Plan
Airport stand allocated for each tail for each task

isAllowed (activity, stand)
costScore (activity, stand)

Rule Engine



Rules

- Tail & Stand Compatibility *"tail can park on stand'*
- Activity & Stand Preference *"planes can park 4 to 6 hours on certain stands"*
- Flight & Stand Compatibility *"flight boarding needs security gate"*
- Ground time rules *"planes needs to be on stand 120 min for departure"*
- Flight & Stand Preference *"temperature critical flights should be allocated on runway side contact stands"*
- PAX / BAG connection rules *"prioritize connection time for certain types of passengers"*

Formulation 1 : GASP

The Math

$x_{s,f}$: Binary Variable If Stand S is allocated to Flight f

$Z_{s,f1,f2}$: Binding Binary Variable If Stand S is allocated to Flight f1 and Flight f2, where f1 and f2 are a tail-turn

$C_{s,f}$: Stand – Flight Preference Score

$$\text{Min} \sum C_{s,f} x_{s,f} + \sum \text{PaxCount}_{f1,f2} * \text{PaxTransferTime}_{s1,s2} \, x_{s1,f1} \, x_{s2,f2} - Z_{s,f1,f2}$$

Gate Compatibility & Utilization

Minimize Passenger Travel

Minimize Tows

Subject to constraints:

Flight Assignment : For f € F: $\sum x_{s,f} = 1$

Stand Availability : For s € S, Flight pairs f1 and f2 which overlap : $x_{s,f1} + x_{s,f2} <= 1$

XZBrigde Constraints : $Z_{s,f1,f2}$ is on iff $x_{s,f1}$ and $x_{s,f1}$ are on where f1,f2 are a tail-turn

Formulation 1 : GASP Towards a more complete and Linearized Model

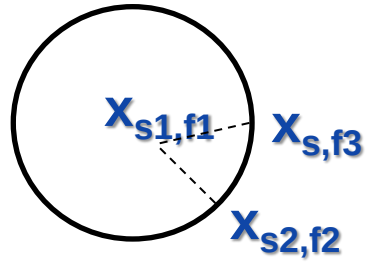
The Math

$x_{s,f}$: Binary Variable If Stand S is allocated to **Task** f

$Z_{s,f1,f2}$: Binding Binary Variable If Stand S is allocated to Task f1 and Task f2, where f1 and f2 are a tail-turn

$C_{s,f}$ **:** Stand – Task Preference Score (Rules Engine)

paxTPenalty $_{s,f1,f2}$: A variable which turns on when f1,f2 are not assigned to „good“ stands



$$\text{Min } w1 \sum C_{s,f} x_{s,f} + \quad w2 \sum \text{paxTPenalty}_{s,f1,f2} \quad - \quad w3\, Z_{s,f1,f2}$$

Gate Compatibility & Utilization

Passenger Unhappiness

Minimize Tows

Subject to constraints:

Task Assignment : For task f € F: $\sum x_{s,f} = 1$

Stand Availability : For stand s € S, Task pairs f1 and f2 which overlap : $x_{s,f1} + x_{s,f2} <= 1$

XZBrigde Constraints : $Z_{s,f1,f2}$ is on iff $x_{s,f1}$ and $x_{s,f1}$ are on where f1,f2 are a tail-turn

Max number of tows per hour : For hour h € H, f1,f2 € F in H : $\text{TailTurns}_h - \sum z_{s,f1,f2} <= \text{MaxTows}(h)$

Minimize Cross-runways tows :

Fix Pre-Assignments from Previous Stand Plan or current Plan for Recovery : $x_{s,f} = 1$

Formulation 2 : Column Generation

The Math

$x_{s,t}$: Binary Variable If Generated Tail Schedule(Column) s is allocated to Tail t

$C_{s,t}$: **Tail Schedule Score** (Rules Engine)

$$\textbf{Min} \sum C_{s,t}\, x_{s,t}$$

Subject to constraints:

Flight Assignment : For tail t € T: $\sum x_{s,t} = 1$

Stand Availability : For time i, For schedules s € S which overlap at time i : $\sum x_{s,t} <= 1$

Max number of tows per hour : For hour h € H, s in schedules and it has tow in h : $\sum x_{s,t} <=$ MaxTows(h)

Minimize Cross-runways tows :

Fix Pre-Assignments from Previous Stand Plan or current Plan for Recovery : $x_{s,t} = 1$

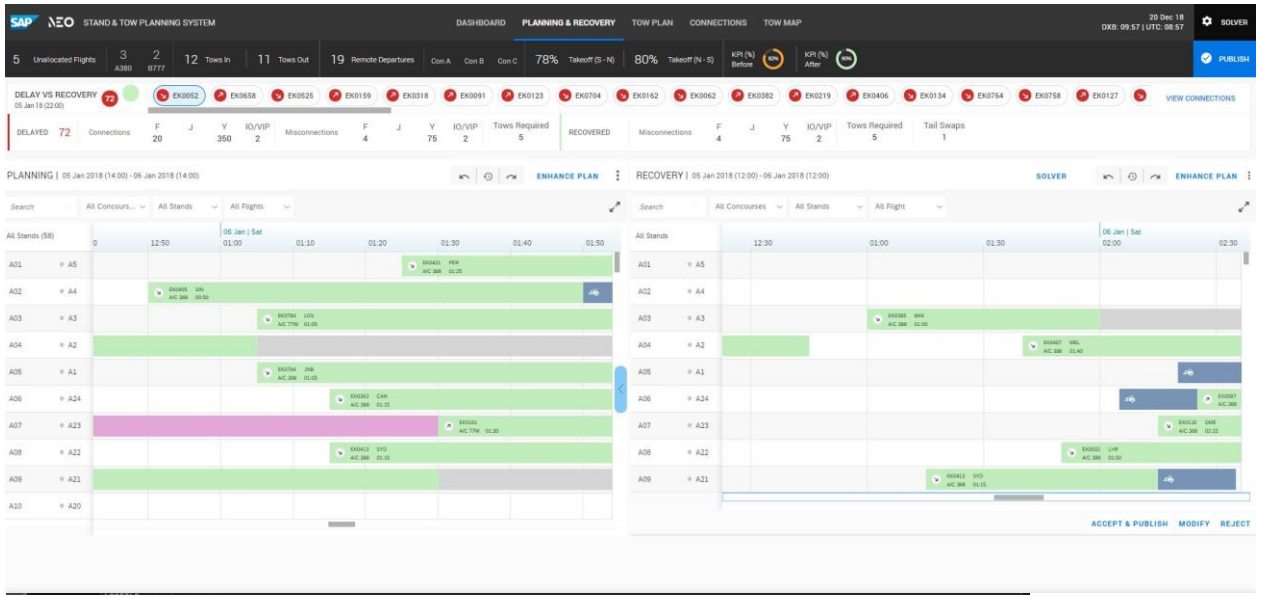
Generate new schedules for Tail t which include options to swap flights

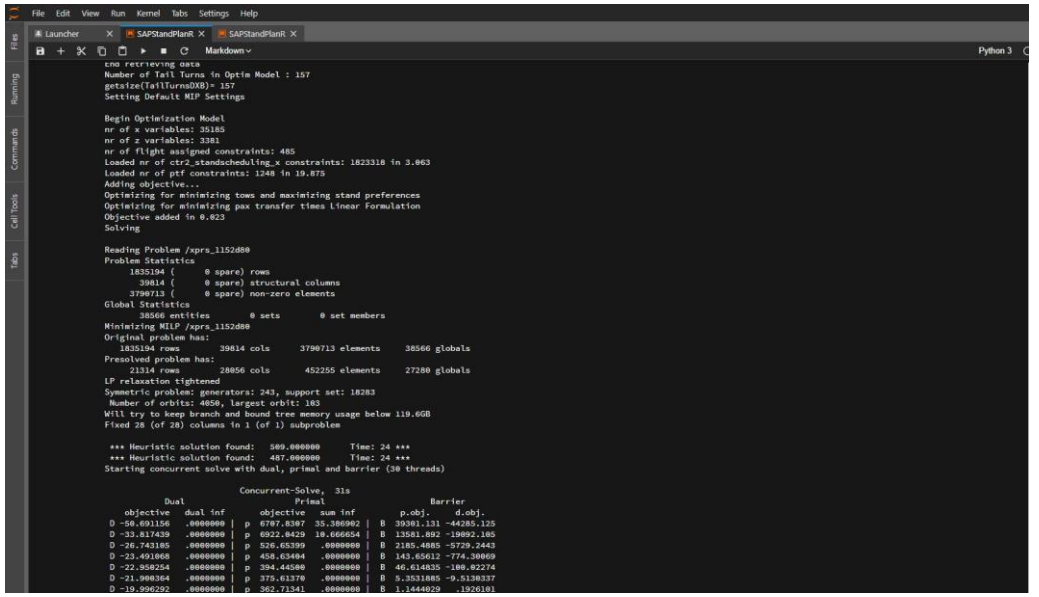
Data Statistics

- Planning Horizon : 12-24 Hours
- Number of Stands : 130
- Number of Flights : 400
- Number of Non-Flight Tasks : 80
- Number of Tail Schedules Generated(Column Generation) : 18 Million which then reduced by Smarter Generation

Performance Figures

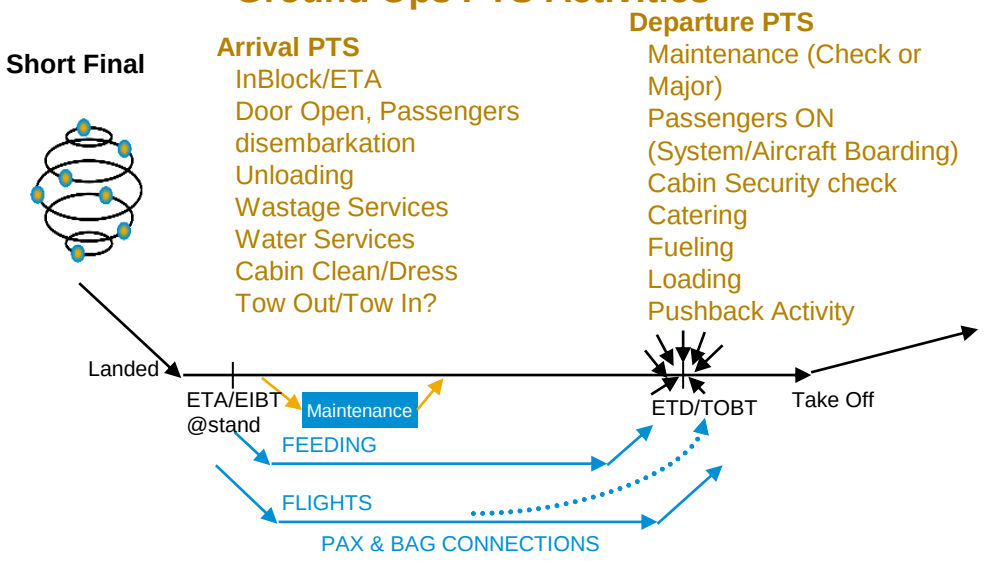
- Formulation 1 : < 2 minutes
- Formulation 2 :
  - Overall path generation and filtering ~2 minutes
  - Optimal solution time ~50 seconds
  - Total solution time ~3 minutes





Turn Around Operations Scheduling & Target Off-Block Time (TOBT) Prediction

Ground Ops PTS Activities



for any PTS Scenario, any EIBT,
Q1: what is TOBT ?

Q2: what are start/end times of each ground task ?

Q3: what happens to TOBT when delays occur :
- a. at EIBT (Q1) ?
- b. at any task (start/end/duration delay) ?

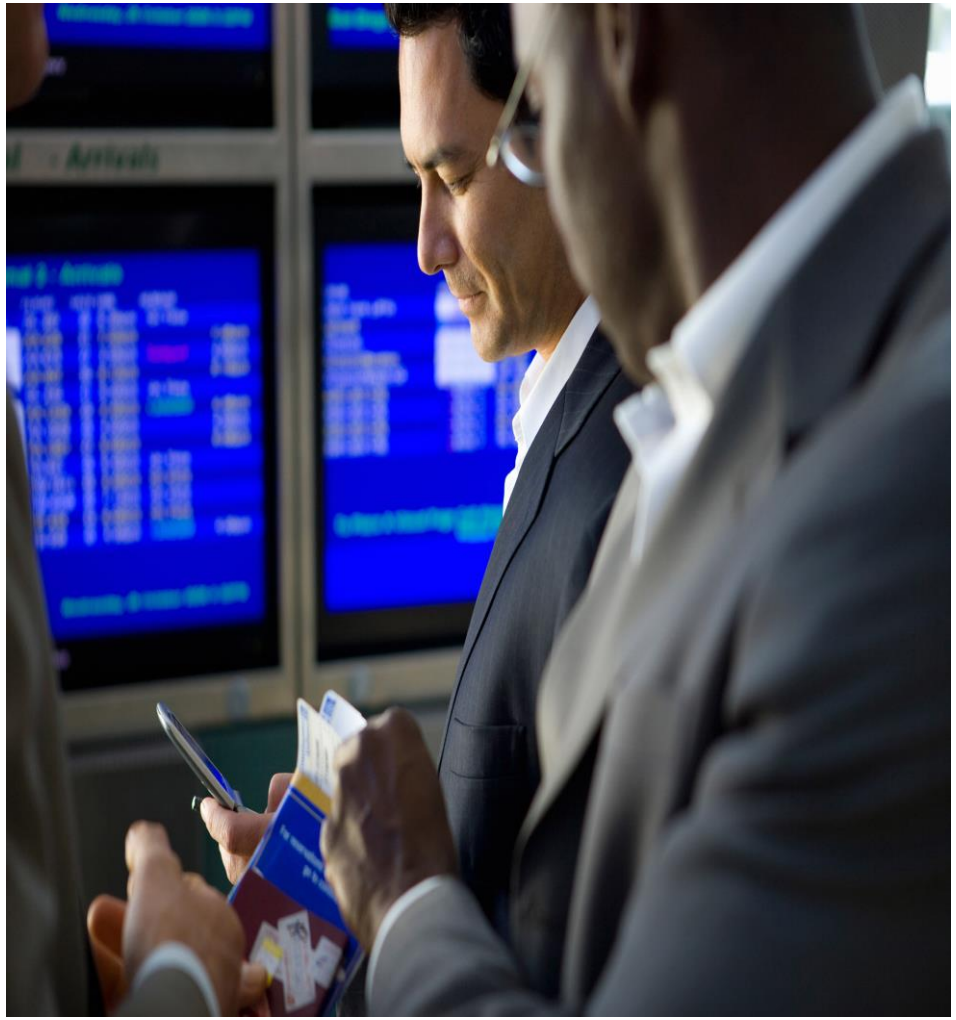
Q4: are there Recovery / Mitigation actions which protect TOBT / OTP ?

Many PTS precedence Graph Scenarios/rules: for example, if ground time < 120 mns & arrival & departure same stand :

	Process	Activity	Dependency	Milestone
		ARRIVAL		
1	Readiness	Despatcher at bay		ETD-115
2	Aircraft	In-blocks	1	ETD-105
4	Passenger	Cabin door open by crew	2	
5	Passenger	Passengers disembarkation	4	
6	Cleaning	Cabin Clean/Dress	5	
		DEPARTURE		
7	Passenger	Gate Open		ETD-90
8	Passenger	Passengers On (System Boarding)	7	
9	Catering	Catering	5	
10	Crew	Crew On board	5	ETD - 60
11	Security	Cabin Security Check	6,9,10	
12	Passenger	Passenges On (Aircraft Boarding)	11,8 S to S	
13	Aircraft	Cabin door closed by Crew (-3)	12	ETD -3
		ARRIVAL		
14	Technical Services	Wastage Services	2	
15	Unloading	Belly door open	2	inblock+1
16	UnLoading	Ramp Equipment connected	15	
17	UnLoading	Unload (Sub Tasks)	16	
		Departure		
18	Technical Services	Water Services	14	
19	Fuelling	Fuelling	5	
20	Loading	LIRF Received		ETD-90
21	Loading	Last Baggage ULD positioned at bay (-20)		ETD-20
22	Loading	Last Bulk Baggage positioned at the bay(-10)		ETD-10
23	Loading	Last Cargo ULD Positioned at bay(-30)		ETD-30
24	Loading	Loading (Sub tasks)	17,20 , (21, 22, 23 (F to F))	
25	Aircraft	Belly Door close -3 milestone	24	ETD-3
26	Loading	Load Sheet Acceptance	10,19,20	ETD-5
27	Technical Services	Pushback Activity (-10)	13,25,26	
28	Aircraft	Offblock	27	OFF BLOCK

Business Challenges – Ops Monitoring & TOBT Prediction

- Monitoring of Ground Operations (Airport View) across all asset classes/events/activities in real time and in a single view
  - Emirates knows much about their ground operations in real time, but the information about all the locations and the progressive status of the activities is not available in real time to achieve On Time Performance.
- Understanding existing durations, dependencies and delays of each and every activity for Ground Operations in real time
- Generate a realistic TOBT (Target off Bock Time) / RTG (Ready to Go) through early prediction of deviations in the ground
- Big number of Silos/Systems for analysis across all Ground Operations
  - Understanding Target Off Block Time based on past behavior, historical effect on the same flight, route and plan.



Apply appropriate Aircraft PTS Turn Around Scenario:
Ground Time > 120 mn => PTS split into Arrival PTS separate from Departure PTS :

TASKNR	PROCESS	ACTIVITY	DEPENDENCY	MILESTONE	PLAN_ST	DURATION	A	SC	ARR	ABOV	PTS_SCE	UI_SEQ_I
1	Readiness	Dispatcher at bay		ETA-10	ETA-10	0		A	A		11	
2	Aircraft	In-blocks	1	ETA	ETA	0		A	A		11	
3	Passenger	Loading, Bridges Docking	2	ETA	ETA	2		A	A		11	
4	Passenger	Cabin door open by crew	3	ETA+2	ETA+2	1		A	A		11	
5	Passenger	Passengers disembarkation	4	ETA+3	ETA+3	15		A	A		11	
29	Catering	catering off load	5	ETA+18	ETA+18	15		A	A		11	
6	Cleaning	Cabin Clean/Dress	5	ETA+18	ETA+18	45		A	A		11	
14	Technical Services	Wastage Services	3	ETA+2	ETA+2	25		A	B		11	
15	Unloading	Belly door open	2	ETA	ETA	1		A	B		11	
16	Unloading	Ramp Equipment connected	15	ETA+1	ETA+1	2		A	B		11	
17	Unloading	Unload	16	ETA+3	ETA+3	40		A	B		11	
25	Unloading	Belly Door Close	17	ETA+43	ETA+43	1		A	B		11	
13	Passenger	Cabin Door Close	6,29	ETA+63	ETA+63	1		A	A		11	
34	Readiness	End of Arrival	14,13,25	ETA+63	ETA+63	0		A				

PTS Ends when activity 14,13 and 25 completes

PTS | pts_arrival_no_tow | pts_arrival_tow | pts_no_tow_departure | pts_tow_departure | pts_turnaround_no_tow

TASKNR	PROCESS	ACTIVITY	DEPENDENCY	MILESTONE	PLAN_START	ACTIVITY_DU
6	Readiness	Cabin Clean/Dress -Readiness		ETD-97	ETD-97	
14	Readiness	Wastage Services -Readiness		ETD-85	ETD-85	
1	Readiness	Dispatcher at bay		ETD-85	ETD-85	
2	Aircraft	In-blocks	1	ETD-75	ETD-75	
3	Passenger	Loading, Bridges Docking	2	ETD-75	ETD-75	
7	Passenger	Gate Open		ETD-90	ETD-90	
8	Passenger	Passengers On-System Boarding	7	ETD-89	ETD-89	
4	Passenger	Cabin door open	3	ETD-73	ETD-73	
15	Loading	Belly Door Open	2	ETD-73	ETD-73	
9	Catering	Catering -On Load	4	ETD-72	ETD-72	
10	Crew	Crew On board	4	ETD-60	ETD-60	
11	Security	Cabin Security Check	6,9,10	ETD-52	ETD-52	
12	Passenger	Passengers On-Aircraft Boarding	11, 8 (F to F - 10)	ETD-42	ETD-42	
13	Passenger	Cabin door closed by Crew	12	ETD-4	ETD-4	
18	Technical S	Water Services	2,14	ETD-60	ETD-60	
19	Fuelling	Fuelling	2	ETD-70	ETD-70	
16	Loading	Ramp Equipment connected	15	ETD-58	ETD-58	
20	Loading	LIRF Received		ETD-90	ETD-90	
21	Loading	Last Baggage ULD positioned at bay		ETD-20	ETD-20	
22	Loading	Last Bulk Baggage positioned at the bay		ETD-10	ETD-10	
23	Loading	Last Cargo ULD Positioned at bay		ETD-30	ETD-30	
24	Loading	Loading (Sub tasks)	16,20, 21 (F to F), 22 (F to F), 23 (F to F)	ETD-60	ETD-60	
25	Loading	Belly Door Closed	24	ETD-5	ETD-5	
26	Loading	Load Sheet Acceptance	10,18,19,20	ETD-15	ETD-15	
27	Technical S	Pushback Activity	13,25,26	ETD-3	ETD-3	
28	Aircraft	Off-block	27, 8 (F to F - 15)	ETD	ETD	

PTS | pts_arrival_no_tow | pts_arrival_tow | pts_no_tow_departure | pts_tow_departure | pts_turnaround_no_tow

Ground Time (Tail Plan) and Stand & Tow Plan dictate which PTS Scenario/PERT GRAPH to use for each Aircraft Turn

Apply appropriate Aircraft PTS Turn Around Scenario:
Ground Time > 120 mn => PTS split into Arrival PTS separate from Departure PTS :

TASKNR	PROCESS	ACTIVITY	DEPENDENCY	MILESTON	PLAN_START	ACTIVITY_	DURATION	ACTIVIT
1	Readiness	Dispatcher at bay		ETA-10	ETA-10		0	
2	Aircraft	In-blocks	1	ETA	ETA		0	
3	Passenger	Loading, Bridges Docking	2	ETA	ETA		2	
4	Passenger	Cabin door open by crew	3	ETA+2	ETA+2		1	
5	Passenger	Passengers disembarkation	4	ETA+3	ETA+3		15	
29	Catering	catering off load	5	ETA+18	ETA+18		15	
6	Cleaning	Cabin Clean/Dress	5	ETA+18	ETA+18		45	
14	Technical Servi	Wastage Services	3	ETA+2	ETA+2		25	
15	Unloading	Belly door open	2	ETA	ETA		1	
16	Unloading	Ramp Equipment connected	15	ETA+1	ETA+1		2	
17	Unloading	Unload	16	ETA+3	ETA+3		40	
25	Unloading	Belly Door Close	17	ETA+43	ETA+43		1	
13	Passenger	Cabin Door Close	6,29	ETA+63	ETA+63		1	
30	Readiness	Pushback Tow team-Readiness		ETA+54	ETA+54		0	
31	Aircraft	Pushback Tow Engagement	25,13,30,14	ETA+64	ETA+64		f(standA,standB), default: 10	

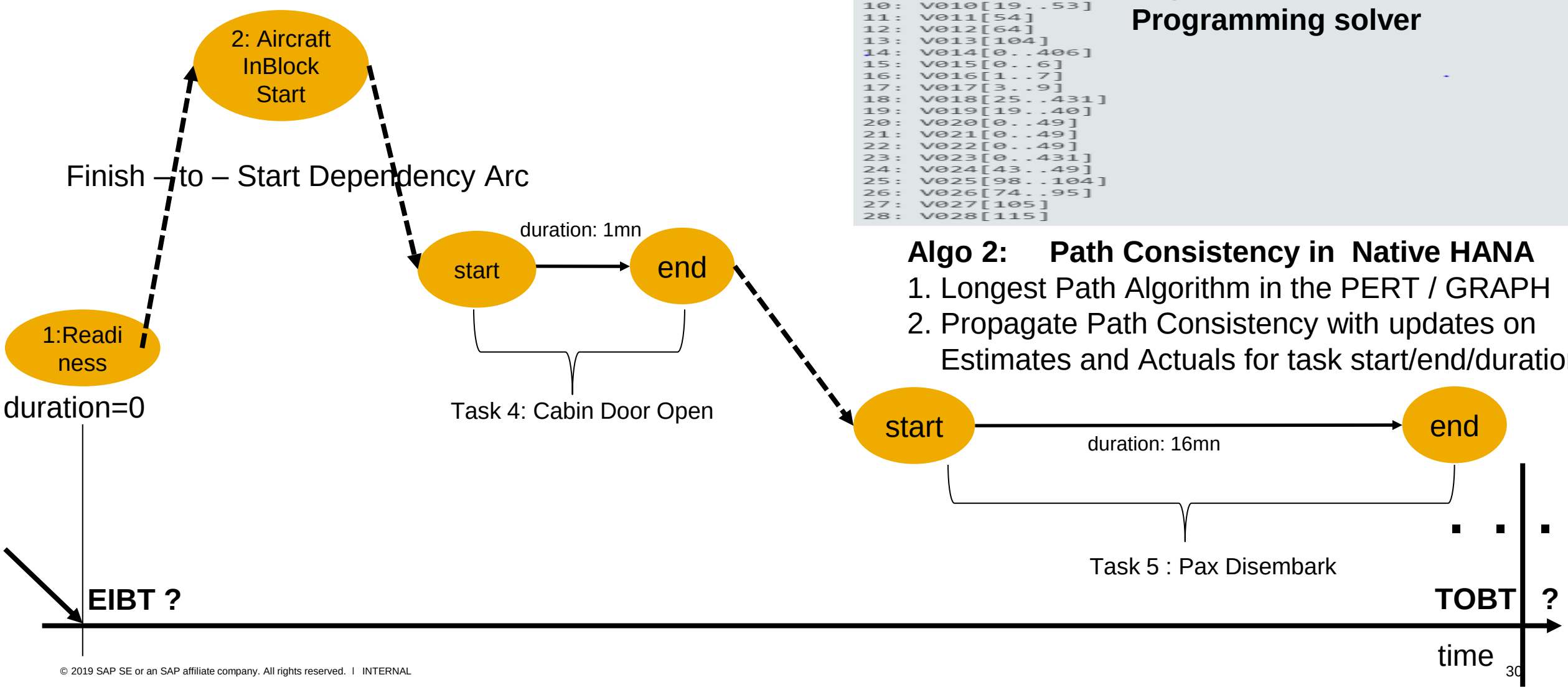
PTS | pts_arrival_no_tow | **pts_arrival_tow** | pts_no_tow_departure | pts_tow_departure | pts_turnaround_no_tow

WITH TOW OUT / TOW IN
… from Stand and Tow Plan

1	Readiness	Dispatcher at bay	ETD-85	ETD-85
2	Aircraft	In-blocks	33,1 ETD-75	ETD-75
3	Passenger	Loading, Bridges Docking	2 ETD-75	ETD-75
7	Passenger	Gate Open	ETD-90	ETD-90
8	Passenger	Passengers On-System Board	7 ETD-89	ETD-89
4	Passenger	Cabin door open	3 ETD-73	ETD-73
15	Loading	Belly Door Open	2 ETD-73	ETD-73
9	Catering	Catering -On Load	4 ETD-72	ETD-72
10	Crew	Crew On board	4 ETD-60	ETD-60
11	Security	Cabin Security Check	9,10,6 ETD-52	ETD-52
12	Passenger	Passengers On-Aircraft Board	11, 8 (F to F - 10) ETD-42	ETD-42
13	Passenger	Cabin door closed by Crew	12 ETD-4	ETD-4
18	Technical Services	Water Services	2, 14 ETD-60	ETD-60
19	Fuelling	Fuelling	2 ETD-70	ETD-70
16	Loading	Ramp Equipment connected	15 ETD-58	ETD-58
20	Loading	LIRF Received	ETD-90	ETD-90
21	Loading	Last Baggage ULD positioned at bay	ETD-20	ETD-20
22	Loading	Last Bulk Baggage positioned at the bay	ETD-10	ETD-10
23	Loading	Last Cargo ULD Positioned at bay	ETD-30	ETD-30
24	Loading	Loading (Sub tasks)	16,20, 21 (F to F), 22 (F to F), 23 (F to F) ETD-60	ETD-60
25	Loading	Belly Door Closed	24 ETD-5	ETD-5
26	Loading	Load Sheet Acceptance	10,18, 19,20 ETD-15	ETD-15
27	Technical Services	Pushback Activity	13,25,26 ETD-3	ETD-3
28	Aircraft	Off-block	27,8 (F to F - 15) ETD	ETD

PTS | pts_arrival_no_tow | pts_arrival_tow | pts_no_tow_departure | **pts_tow_departure** | pts_turnaround_no_tow

Node Task Start, Node Task End, Task Arc (Milestones are Tasks with duration 0) :



b1ek.3.mos - St

TOBT Computation Engine : Constraint Satisfaction Mode

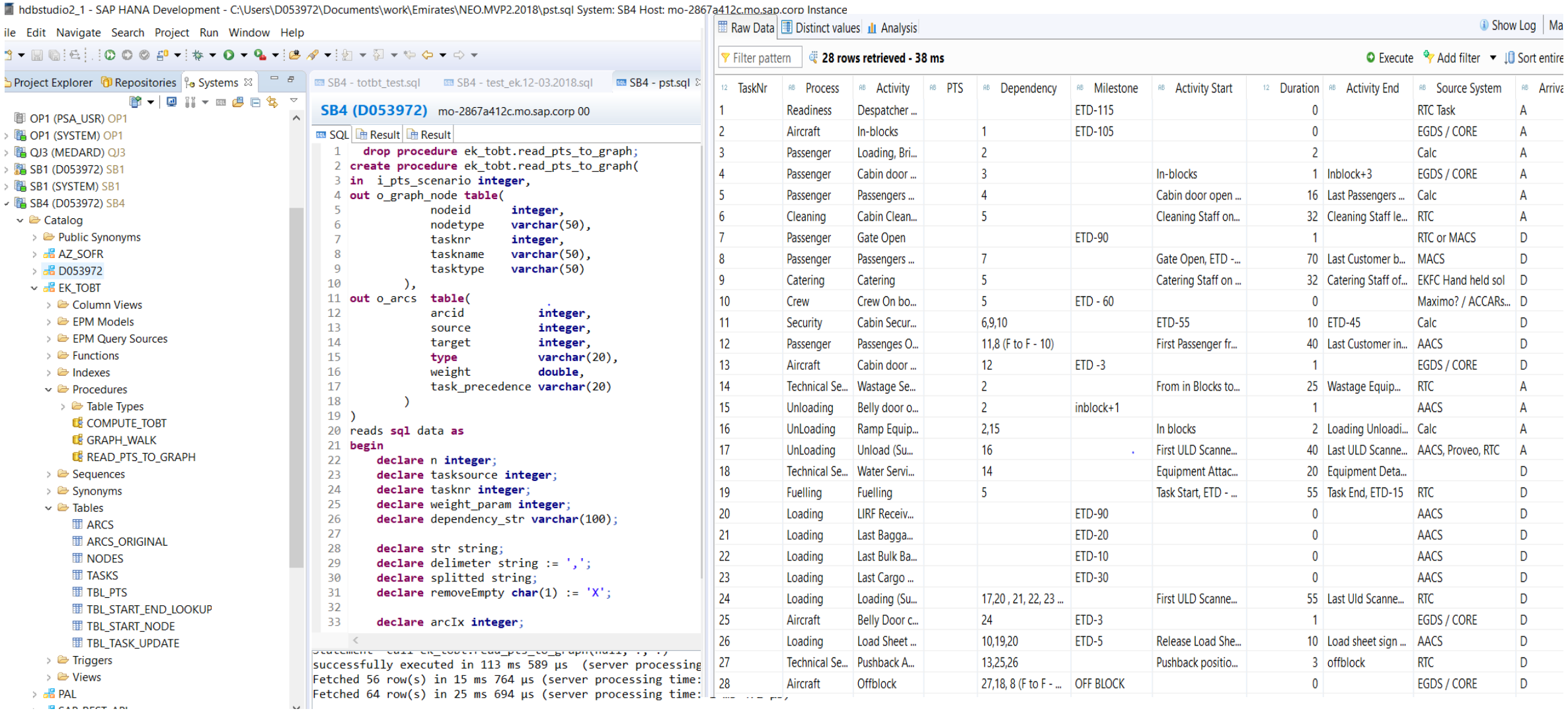
```
Running model
Earliest possible completion time: 115
1: V001[0]
2: V002[0]
3: V003[0]
4: V004[2]
5: V005[3]
6: V006[19]
7: V007[0..33]
8: V008[1..34]
9: V009[19]
10: V010[19..53]
11: V011[54]
12: V012[64]
13: V013[104]
14: V014[0..406]
15: V015[0..6]
16: V016[1..7]
17: V017[3..9]
18: V018[25..431]
19: V019[19..40]
20: V020[0..49]
21: V021[0..49]
22: V022[0..49]
23: V023[0..431]
24: V024[43..49]
25: V025[98..104]
26: V026[74..95]
27: V027[105]
28: V028[115]
```

Algo 1: Constraint Programming solver

Algo 2: Path Consistency in Native HANA

1. Longest Path Algorithm in the PERT / GRAPH
2. Propagate Path Consistency with updates on Estimates and Actuals for task start/end/duration

For Each Aircraft Turn Around, Create a PTS PERT Model/Graph



TaskNr	Process	Activity	PTS	Dependency	Milestone	Activity Start	Duration	Activity End	Source System	Arriva
1	Readiness	Despatcher ...			ETD-115		0		RTC Task	A
2	Aircraft	In-blocks		1	ETD-105		0		EGDS / CORE	A
3	Passenger	Loading, Bri...		2			2		Calc	A
4	Passenger	Cabin door ...		3		In-blocks	1	Inblock+3	EGDS / CORE	A
5	Passenger	Passengers ...		4		Cabin door open ...	16	Last Passengers ...	Calc	A
6	Cleaning	Cabin Clean...		5		Cleaning Staff on...	32	Cleaning Staff le...	RTC	A
7	Passenger	Gate Open			ETD-90		1		RTC or MACS	D
8	Passenger	Passengers ...		7		Gate Open, ETD -...	70	Last Customer b...	MACS	D
9	Catering	Catering		5		Catering Staff on ...	32	Catering Staff of...	EKFC Hand held sol	D
10	Crew	Crew On bo...		5	ETD - 60		0		Maximo? / ACCARs...	D
11	Security	Cabin Secur...		6,9,10		ETD-55	10	ETD-45	Calc	D
12	Passenger	Passenges O...		11,8 (F to F - 10)		First Passenger fr...	40	Last Customer in...	AACS	D
13	Aircraft	Cabin door ...		12	ETD -3		1		EGDS / CORE	D
14	Technical Se...	Wastage Se...		2		From in Blocks to...	25	Wastage Equip...	RTC	A
15	Unloading	Belly door o...		2	inblock+1		1		AACS	A
16	UnLoading	Ramp Equip...		2,15		In blocks	2	Loading Unloadi...	Calc	A
17	UnLoading	Unload (Su...		16		First ULD Scanne...	40	Last ULD Scanne...	AACS, Proveo, RTC	A
18	Technical Se...	Water Servi...		14		Equipment Attac...	20	Equipment Deta...		D
19	Fuelling	Fuelling		5		Task Start, ETD - ...	55	Task End, ETD-15	RTC	D
20	Loading	LIRF Receiv...			ETD-90		0		AACS	D
21	Loading	Last Bagga...			ETD-20		0		AACS	D
22	Loading	Last Bulk Ba...			ETD-10		0		AACS	D
23	Loading	Last Cargo ...			ETD-30		0		AACS	D
24	Loading	Loading (Su...		17,20 , 21, 22, 23 ...		First ULD Scanne...	55	Last Uld Scanne...	RTC	D
25	Aircraft	Belly Door c...		24	ETD-3		1		EGDS / CORE	D
26	Loading	Load Sheet ...		10,19,20	ETD-5	Release Load She...	10	Load sheet sign ...	AACS	D
27	Technical Se...	Pushback A...		13,25,26		Pushback positio...	3	offblock	RTC	D
28	Aircraft	Offblock		27,18, 8 (F to F - ...	OFF BLOCK		0		EGDS / CORE	D

This PTS is for an Aircraft Turn of less than 120 mns with no tow : aircraft occupies stand from the moment it arrives with arrival flight until it departs on its connecting flight.

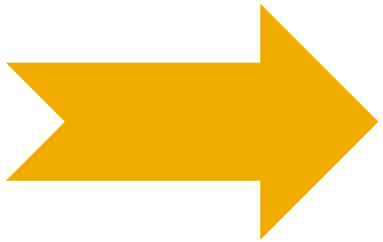
Forward Walk in the PERT/GRAPH with data updates gives Lower Bounds = Earliest start times for each node

SB4 (D053972) mo-2867a412c.mo.sap.corp 00

SQL | Result

```
select * from ek_tobt.tbl_task_update
```

	TASKID	START_TIME	END_TIME	DURATION
1	6	?	?	42



SQL | Result

```
call ek_tobt.compute_tobt()
```

	ENDID	TASKID	WEIGHT_TOTAL
1	2	1	0
2	3	2	0.01
3	4	2	0.01
4	5	3	0.02
5	6	3	2.02
6	7	4	2.03
7	8	4	3.03
8	9	5	3.0399999999...
9	10	5	19.04
10	11	6	19.05
11	12	6	61.05
12	14	7	1
13	15	8	1.01
14	16	8	71.01
15	17	9	19.05
16	18	9	51.05
17	19	10	19.05
18	20	10	19.05
19	21	11	61.059999999...
20	22	11	71.06
21	23	12	71.070000000...
22	24	12	111.07000000...

SQL | Result

```
call ek_tobt.compute_tobt()
```

	ENDID	TASKID	WEIGHT_TOTAL
29	31	16	1.03
30	32	16	3.0300000000...
31	33	17	3.04
32	34	17	43.04
33	35	18	25.03
34	36	18	45.03
35	37	19	19.05
36	38	19	74.05
37	40	20	0
38	42	21	0
39	44	22	0
40	46	23	0
41	47	24	43.05
42	48	24	98.05
43	49	25	98.06
44	50	25	99.06
45	51	26	74.06
46	52	26	84.06
47	53	27	112.09000000...
48	54	27	115.09000000...
49	55	28	115.10000000...
50	56	28	115.10000000...

Data update: Cleaning is delayed by 10 minutes (duration data update): TOBT becomes delayed also by 10mns to 115mns (note original TOBT was 105 mns)

Q: Now, What happens if we perform a Backwards Walk starting from the End Node task 28/TOBT ?

Backward Walk gives Upper Bounds
SO: we ve implemented a constraint solver yielding both Lower and Upper Bounds for start times at each node/Task of the Graph

	TASKID	MIN_START	MIN_END
1	1	0	0
2	2	0	0
3	3	0	2
4	4	2	3
5	5	3	19
6	6	19	51
7	7	1	1
8	8	1	71
9	9	19	51
10	10	19	19
11	11	51	61
12	12	61	101
13	13	101	102
14	14	0	25
15	15	0	1
16	16	1	3
17	17	3	43
18	18	25	45
19	19	19	74
20	20	0	0
21	21	0	0
22	22	0	0
23	23	0	0
24	24	43	98
25	25	98	99
26	26	74	84
27	27	102	105
28	28	105	105

Task 4: LB = 2mn , UB = 3mns, an interval

Task 28: TOBT: LB = UB = 105mns, unique value

Machine Learning Estimates of Task Durations

Agreed PTS with Business

	Process	Activity	Dependency	Milestone
		ARRIVAL		
1	Readiness	Despatcher at bay		ETD-115
2	Aircraft	In-blocks	1	ETD-105
4	Passenger	Cabin door open by crew	2	
5	Passenger	Passengers disembarkation	4	
6	Cleaning	Cabin Clean/Dress	5	
		DEPARTURE		
7	Passenger	Gate Open		ETD-90
8	Passenger	Passengers On (System Boarding)	7	
9	Catering	Catering	5	
10	Crew	Crew On board	5	ETD - 60
11	Security	Cabin Security Check	6,9,10	
12	Passenger	Passenges On (Aircraft Boarding)	11,8 S to S	
13	Aircraft	Cabin door closed by Crew (-3)	12	ETD -3
		ARRIVAL		
14	Technical Services	Wastage Services	2	
15	Unloading	Belly door open	2	inblock+1
16	UnLoading	Ramp Equipment connected	15	
17	UnLoading	Unload (Sub Tasks)	16	
		Departure		
18	Technical Services	Water Services	14	
19	Fuelling	Fuelling	5	
20	Loading	LIRF Received		ETD-90
21	Loading	Last Baggage ULD positioned at bay (-20)		ETD-20
22	Loading	Last Bulk Baggage positioned at the bay(-10)		ETD-10
23	Loading	Last Cargo ULD Positioned at bay(-30)		ETD-30
24	Loading	Loading (Sub tasks)	17,20 , (21, 22, 23 (F to F))	
25	Aircraft	Belly Door close -3 milestone	24	ETD-3
26	Loading	Load Sheet Acceptance	10,19,20	ETD-5
27	Technical Services	Pushback Activity (-10)	13,25,26	
28	Aircraft	Offblock	27	OFF BLOCK

Unloading and Loading ML Prediction Models Design

Targets: Tails with known unloading total duration / Tails with known loading total duration

Explanatory Variables:

- ✓ Flight details: bay, pax loads, flight route (origin / destination), aircraft capacity
- ✓ Calendar details (day of the week, month)
- ✓ Historical unloading times , Belly door open event start – RTC End task (>=6 months history)
- ✓ Historical loading times , 1st uld scanned – Last uld scanned at the bay (>=6 months history)

Please note that models can only be developed if there is sufficient cases / data volume

Static PTS

	TaskNr	Process	Activity	Dependency	Duration
1	1	Readiness	Despatcher at bay		0
2	2	Aircraft	In-blocks	1	0
3	3	Passenger	Loading, Bridges Docking	2	2
4	4	Passenger	Cabin door open by crew	3	1
5	5	Passenger	Passengers disembarkation	4	16
6	6	Cleaning	Cabin Clean/Dress	5	32
7	7	Passenger	Gate Open		1
8	8	Passenger	Passengers On (System Boarding)	7	70
9	9	Catering	Catering	5	32
10	10	Crew	Crew On board	5	0
11	11	Security	Cabin Security Check	6,9,10	10
12	12	Passenger	Passenges On (Aircraft Boarding)	11,8 (F to F - 10)	40
13	13	Passenger	Cabin door closed by Crew (-3)	12	1
14	14	Technical Services	Wastage Services	2	25
15	15	Unloading	Belly door open	2	1
16	16	UnLoading	Ramp Equipment connected	2,15	2
17	17	UnLoading	Unload (Sub Tasks)	16	40
18	18	Technical Services	Water Services	14	20
19	19	Fuelling	Fuelling	5	55
20	20	Loading	LIRF Received		0
21	21	Loading	Last Baggage ULD positioned at bay (-20)		0
22	22	Loading	Last Bulk Baggage positioned at the bay(-10)		0
23	23	Loading	Last Cargo ULD Positioned at bay(-30)		0
24	24	Loading	Loading (Sub tasks)	17,20 , 21, 22, 23 (F to F)	55
25	25	Loading	Belly Door close -3 milestone	24	1
26	26	Loading	Load Sheet Acceptance	10,19,20	10
27	27	Technical Services	Pushback Activity (-10)	13,25,26	3
28	28	Aircraft	Offblock	27,18, 8 (F to F - 15)	0

Relative Static TA/TOBT plan

	TASKID	MIN_START	MIN_END
1	1	0	0
2	2	0	0
3	3	0	2
4	4	2	3
5	5	3	19
6	6	19	51
7	7	1	1
8	8	1	71
9	9	19	51
10	10	19	19
11	11	51	61
12	12	61	101
13	13	101	102
14	14	0	25
15	15	0	1
16	16	1	3
17	17	3	43
18	18	25	45
19	19	19	74
20	20	0	0
21	21	0	0
22	22	0	0
23	23	0	0
24	24	43	98
25	25	98	99
26	26	74	84
27	27	102	105
28	28	105	105

	TA_START	UNLOAD_START	UNLOAD_END	LOAD_START	LOAD_END	TOBT
1	0	3	43	43	98	105

Example of ML Unloading Duration for flight EK204

Model predicted 30 min for 21st of February

1 rows retrieved - 197 ms

Chart | Table | Grid | HTML

FLIGHT_NO	SCH_DATETIMEUTC	DEPSTN	BAY_NO	rr_TA_UNLOADULD_DOOROPEN_LASTAIRCRFT_SUM
EK0204	2018-02-21 04:10:00.0	JFK	B21R	30.376

But in reality it took 28 min

Chart | Table | Grid | HTML

FLIGHT_NO	SCH_DATETIMEUTC	DEPSTN	BAY_NO	TA_UNLOADULD_DOOROPEN_LASTAIRCRFT_SUM
EK0204	2018-02-21 04:10:00.0	JFK	B21R	28

And according to PTS it was planned for 43 minutes

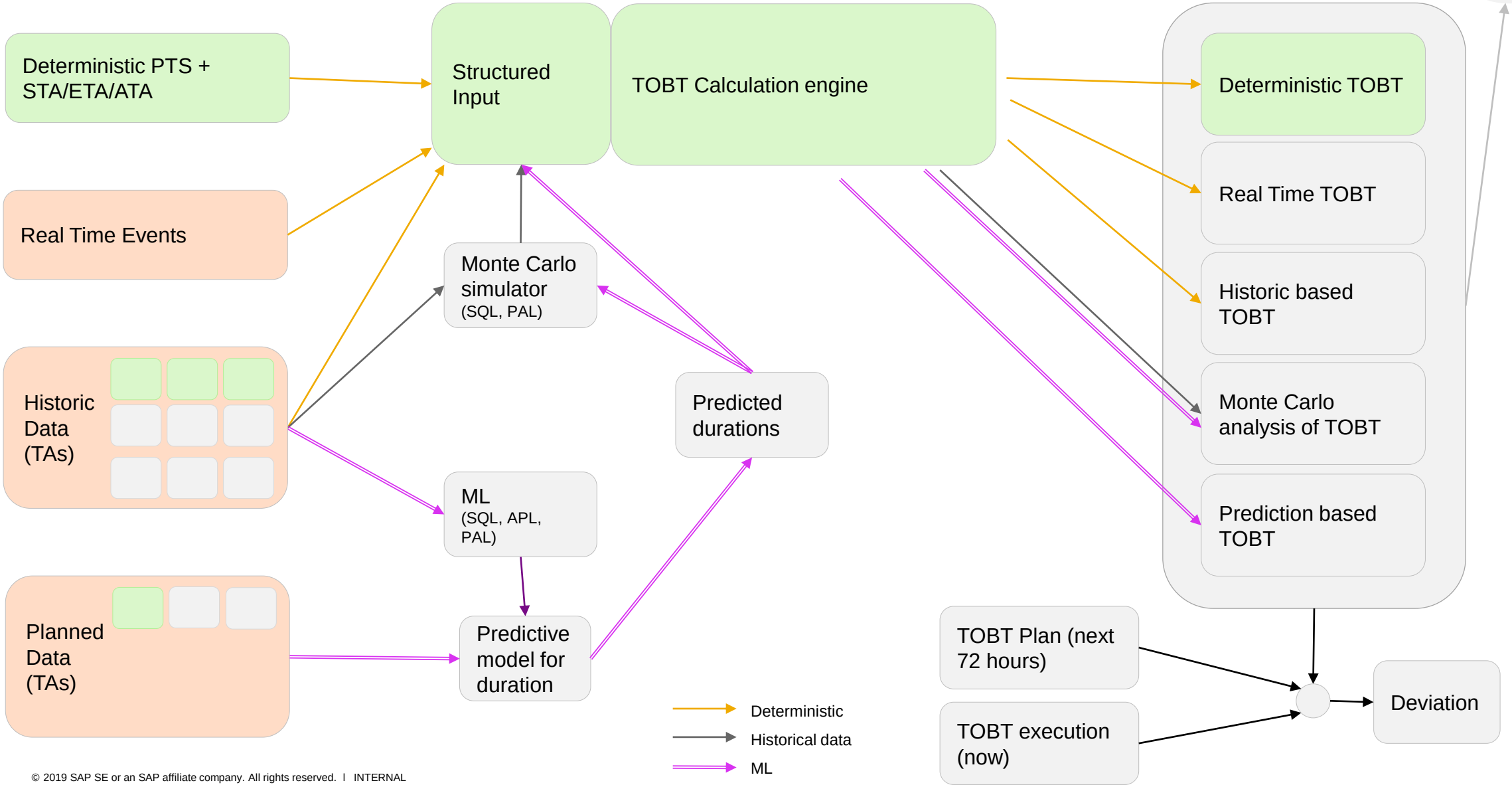
TASKNR	PROCESS	ACTIVITY	DEPENDENCY	DURATION
15	Unloading	Belly door open	2	1
16	Unloading	Ramp Equipment connected	2,15	2
17	Unloading	Unload	16	40

Prediction data (unload+load):

Loading/Unloading ARE flight (Attributes) dependent (thankfully so)

	TAILNO	DEPSTN	TASTN	ARRSTN	FLIGHT_1_NO	TAILNO	DEPSTN	TASTN	ARRSTN	FLIGHT_1_NO	ARR_SCH_DATETIMEUTC	FLIGHT_2_NO	DEP_SCH_DATETIMEUTC	ML_LOAD	ML_UNLOAD
1	A0WNM	JED	DXB	IAD	EK0804	A0WNM	JED	DXB	IAD	EK0804	Feb 21, 2018 8:30:00.0 PM	EK0231	Feb 21, 2018 10:25:00.0 PM	47	30
2	A0WVM	IAD	DXB	AKL	EK0232	A0WVM	IAD	DXB	AKL	EK0232	Feb 20, 2018 4:10:00.0 AM	EK0448	Feb 20, 2018 6:05:00.0 AM	51	30
3	A0WNH	ZRH	DXB	VIE	EK0086	A0WNH	ZRH	DXB	VIE	EK0086	Feb 20, 2018 3:10:00.0 AM	EK0127	Feb 20, 2018 5:00:00.0 AM	39	32
4	A0WLI	BKK	DXB	JFK	EK0419	A0WLI	BKK	DXB	JFK	EK0419	Feb 19, 2018 2:45:00.0 AM	EK0201	Feb 19, 2018 4:30:00.0 AM	46	36
5	A0WVV	BHX	DXB	BKK	EK0038	A0WVV	BHX	DXB	BKK	EK0038	Feb 24, 2018 3:50:00.0 AM	EK0372	Feb 24, 2018 5:30:00.0 AM	46	30
6	A0WFL	SYD	DXB	MAD	EK0415	A0WFL	SYD	DXB	MAD	EK0415	Feb 18, 2018 9:20:00.0 AM	EK0143	Feb 18, 2018 10:40:00.0 A...	67	30
7	A0WNY	MXP	DXB	NCE	EK0092	A0WNY	MXP	DXB	NCE	EK0092	Feb 22, 2018 2:35:00.0 AM	EK0077	Feb 22, 2018 4:20:00.0 AM	68	33
8	A0WVK	CMN	DXB	PER	EK0752	A0WVK	CMN	DXB	PER	EK0752	Feb 23, 2018 9:15:00.0 PM	EK0420	Feb 23, 2018 10:55:00.0 PM	81	32
9	A0WLY	CMN	DXB	PER	EK0752	A0WLY	CMN	DXB	PER	EK0752	Feb 21, 2018 9:15:00.0 PM	EK0420	Feb 21, 2018 10:55:00.0 PM	80	33
10	A0WLZ	LGW	DXB	PVG	EK0010	A0WLZ	LGW	DXB	PVG	EK0010	Feb 20, 2018 3:20:00.0 AM	EK0304	Feb 20, 2018 5:15:00.0 AM	69	29
11	A0WLT	FRA	DXB	BCN	EK0048	A0WLT	FRA	DXB	BCN	EK0048	Feb 24, 2018 1:55:00.0 AM	EK0185	Feb 24, 2018 3:50:00.0 AM	39	37
12	A0WNF	MXP	DXB	JFK	EK0092	A0WNF	MXP	DXB	JFK	EK0092	Feb 24, 2018 2:35:00.0 AM	EK0201	Feb 24, 2018 4:30:00.0 AM	46	35
13	A0WVQ	BCN	DXB	LHR	EK0188	A0WVQ	BCN	DXB	LHR	EK0188	Feb 18, 2018 3:45:00.0 AM	EK0029	Feb 18, 2018 5:40:00.0 AM	39	31
14	A0WVH	JFK	DXB	AKL	EK0204	A0WVH	JFK	DXB	AKL	EK0204	Feb 21, 2018 4:10:00.0 AM	EK0448	Feb 21, 2018 6:05:00.0 AM	49	30
15	A0WNG	SYD	DXB	JED	EK0413	A0WNG	SYD	DXB	JED	EK0413	Feb 18, 2018 1:15:00.0 AM	EK0805	Feb 18, 2018 3:05:00.0 AM	37	32
16	A0WNO	ZRH	DXB	VIE	EK0086	A0WNO	ZRH	DXB	VIE	EK0086	Feb 23, 2018 3:10:00.0 AM	EK0127	Feb 23, 2018 5:00:00.0 AM	43	33
17	A0WNN	JFK	DXB	YYZ	EK0204	A0WNN	JFK	DXB	YYZ	EK0204	Feb 19, 2018 4:10:00.0 AM	EK0241	Feb 19, 2018 5:55:00.0 AM	77	30
18	A0WVC	AMS	DXB	BKK	EK0150	A0WVC	AMS	DXB	BKK	EK0150	Feb 23, 2018 3:45:00.0 AM	EK0372	Feb 23, 2018 5:30:00.0 AM	47	32
19	A0WLY	PER	DXB	JED	EK0421	A0WLY	PER	DXB	JED	EK0421	Feb 23, 2018 1:25:00.0 AM	EK0805	Feb 23, 2018 3:05:00.0 AM	38	36
20	A0WLK	LGW	DXB	FCO	EK0010	A0WLK	LGW	DXB	FCO	EK0010	Feb 24, 2018 3:20:00.0 AM	EK0097	Feb 24, 2018 5:00:00.0 AM	71	30
21	A0WNK	LGW	DXB	BOM	EK0012	A0WNK	LGW	DXB	BOM	EK0012	Feb 19, 2018 4:35:00.0 PM	EK0500	Feb 19, 2018 5:50:00.0 PM	40	30

Challenge #3: More Realistic Task Durations thanks to Machine Learning Models



Relative “ML” TA/TOBT plan

Sensitivity Analysis of updated (ML) durations (...or any other data updates (start/end) :

Identification of Critical Tasks on Critical Paths

Unload: 40*1.23 = 50, Load = 55*1.25 = 68

	TA_START	UNLOAD_START	UNLOAD_END	LOAD_START	LOAD_END	TOBT
1	0	3	53	53	121	125

Unload: 40*0.75 = 30, Load = 55*0.75 = 41

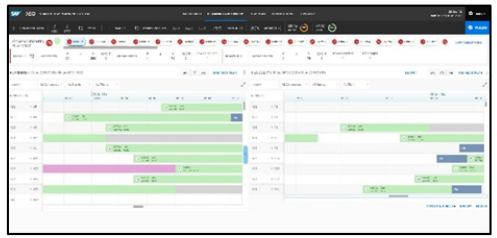
	TA_START	UNLOAD_START	UNLOAD_END	LOAD_START	LOAD_END	TOBT
1	0	3	33	33	74	105

Thanks to constant (every minute) data updates : actuals, estimates, ML durations & Graph Path Consistency recomputation:

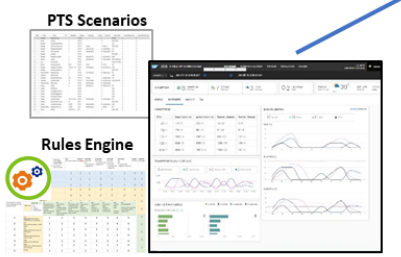
1. Obtain near 100% accuracy of TOBT computations
2. Nice Byproduct of Path Consistency : **TOBT Recovery**: Focusing on which duration/tasks to shrink helps recovering from Operational Delays
   Path consistency is about finding **all critical paths to the end of a project = TOBT** start : Some tasks and durations are critical for TOBT, while many others are not.

Machine Learning & Optimization embedded in the Intelligent Enterprise

Operation Controllers Plan & Recover Stand & Tow Movements



Operation Controllers monitor turnaround process in real-time

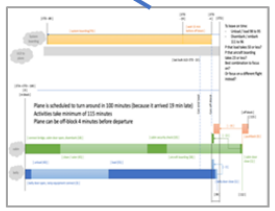


HANA platform holds a unified data model linking

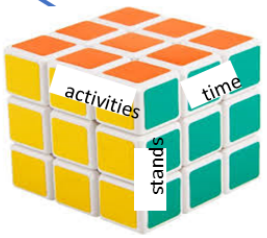
- Flight & Tail Schedule
- Infrastructure
- Maintenance requirements
- Historical data
- IoT data for ground activities
- BHS data…

HANA ML algorithms model the duration of different activities, including information about plane type, outstation, time of the day, origin, gate, no of passengers etc.

HANA graph engine computes feasible start time ranges for all activities and simulates the impact of delays in real-time



Monde Carlo Simulation scenarios reveal expected turnaround duration across all cases



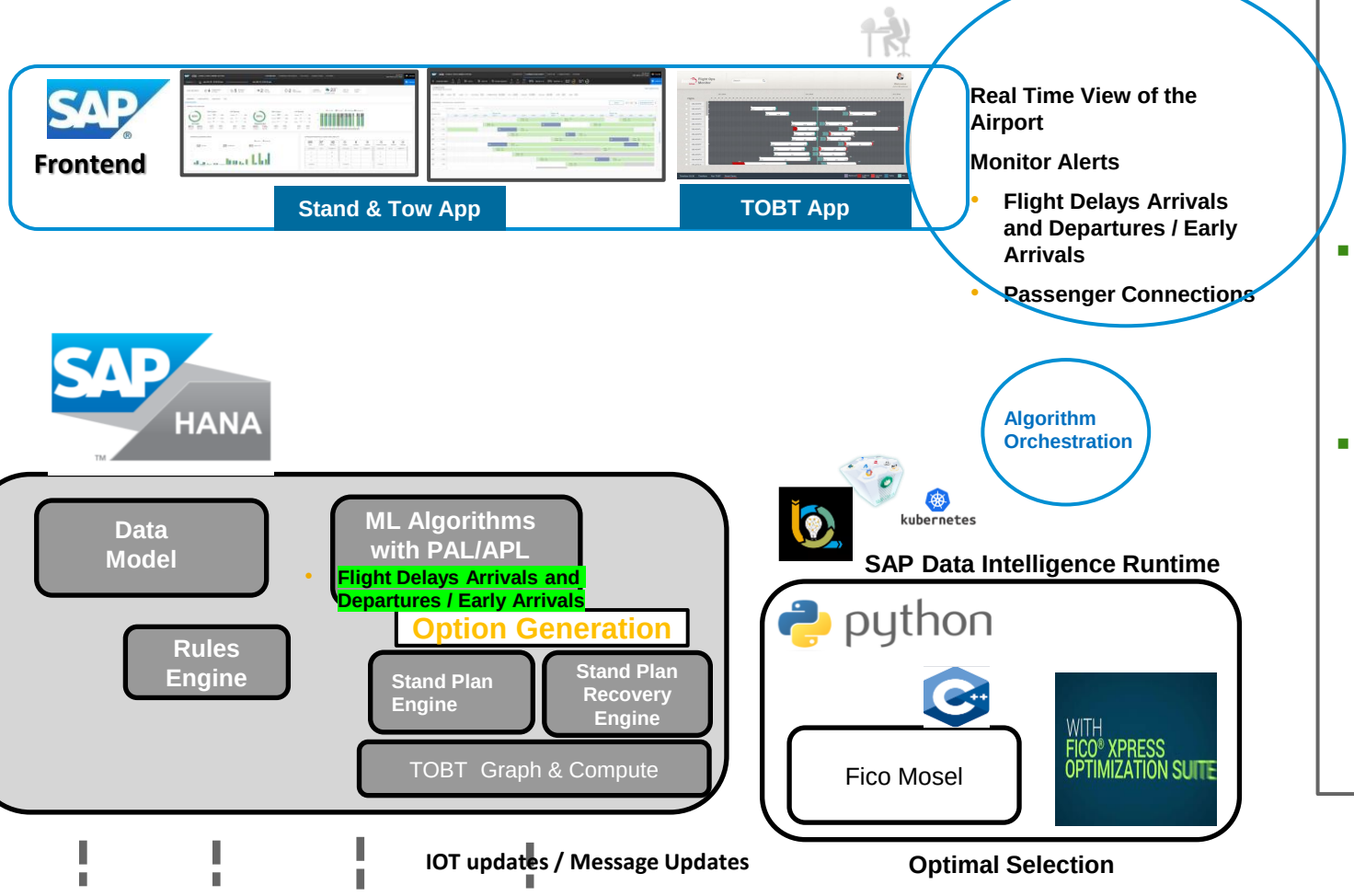
Optimization modeling & algorithms for planning & recovery subject to configurable rules & compatibility requirements

IHC Optimizes stand and remote gate allocations, tow movements, **MUC** allocations for baggage, so as to ensure optimal passenger and bag connections, respect maintenance slot times, and ATC compliant tow movements required for aircraft maintenance and for key stand availability during peak times.

IHC Captures PTS, the complexity and dependencies of all the ground activities that need to be performed to fulfil the flight order from the moment the aircraft hits EIBT until it hits TOBT, **Understands** which activities that are subject to small delays may have significant impact to TOBT delays, **Monitors** actual and ML-predicted duration/start/end times of each activity, and **Computes** their impacts on TOBT.

IHC Monitors all flights landing and departing a hub and all their ground activities impacted by AIBT and AOBT

Stand & Tow & TOBT
High Level Target Architecture



- Optimal Stand Plan with
  - Right number of tows
  - Maximize Contact Stand Utilization
  - Passenger Connectivity
  - Baggage Connectivity
  - Ensuring Tail Maintenance
- Optimal Stand Plan Recovery Engine
  - Ensuring minimizing changes
  - Update plan where incompatible due to changes
- TOBT Planning and recovery (continuous)
  - Compute PTS scenario graphs for each turn around
  - IOT/ML exogenous info data updates
  - Compute start/end times for each ground handling actvitity

Platform Solution Overview

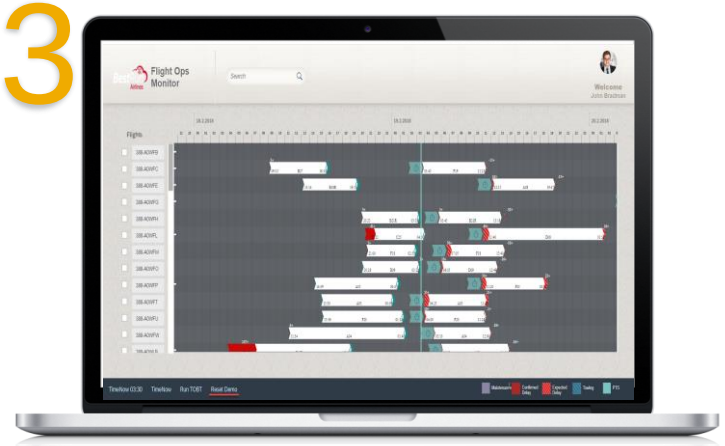
1

Unified Rules Engine Data Model on Hana

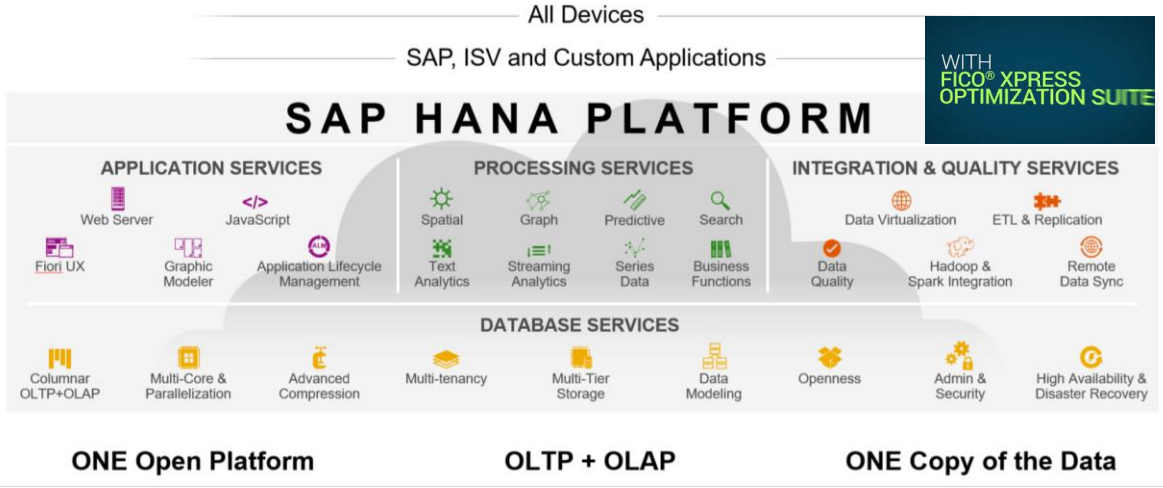
2

Custom optimization & graph algorithms / Column generation on HANA

3



Orchestration & automation & monitoring of planning and recovery



Complex Rules engine model and data modelling

Generated complex ground tasks combinations of an airport including flight and maintenance tasks for any planning horizon
Generated Ground Ops PTS GRAPH for each turnaround

Optimal Stand & Tow Planning and Continuous Recovery

- **by using native HANA data processing and column generation.**
- **Best of breed MIP codes from FICO Express**

Near 100% accuracy of PTS & TOBT predictions

Thank you

Contact information:

Claude Philippe Medard

Principal Data Scientist, GCOE BTP
SAP Deutschland SE
WDF 19 Hasso-Platner Ring, Walldorf 69190, Germany

Mobile +49 151 571 18789
claude.philippe.medard@sap.com

Nidhi Sawhney

Principal Data Scientist, GCOE BTP
SAP Deutschland SE
WDF 19 Hasso-Platner Ring, Walldorf 69190, Germany

Mobile +49 160 904 32749
nidhi.sawhney@sap.com