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ULD Build-Up Scheduling with Dynamic Batching in an Air Freight Hub

Ricardo Euler, Ralf Borndörfer, Timo Strunk, Tuomo Takkula

Zuse Institute Berlin

Ab Ovo Germany GmbH

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ULD Build-Up Scheduling

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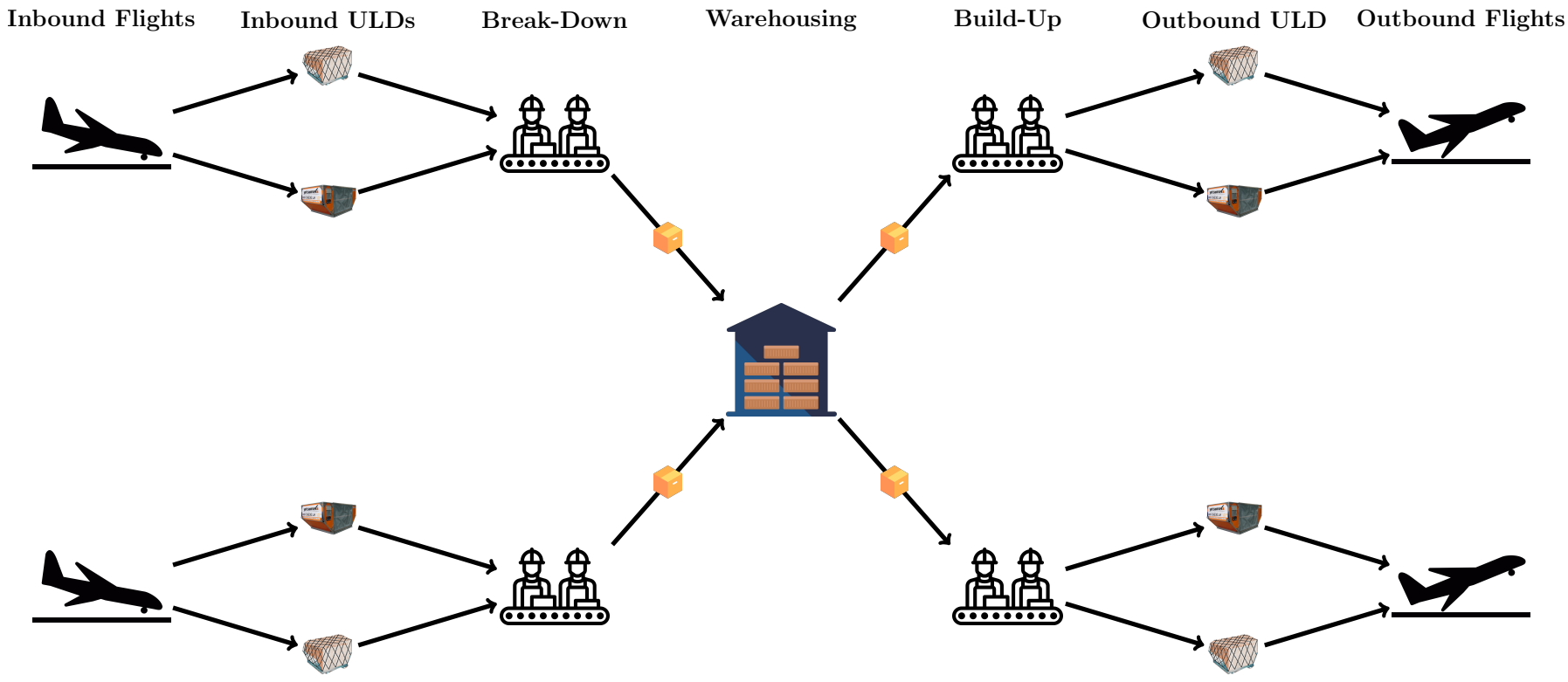

ULD Build-Up Scheduling

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- Schedule all ULD break-downs and build-ups on workstations such that losses from unshipped cargo are minimized
- Respect storage and workstation capacities
- Respect pre-panned ULD per flight
- Build ULD for the same destination in spatial and temporal proximity (not important for break-down procedures)
  - Shipments often come in odd shapes and cannot be stacked arbitrarily
  - Reduces the number of movements necessary between the warehouse and the build-up area
  - Easy model for spatial proximity: Partition workstations into workstation groups

Batch Concept

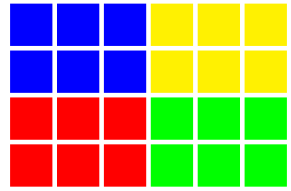

Figure: Floor plan separated in workstation groups

Definition

We refer to a set of identical ULDs for the same flight scheduled at the same time in the same workstation group as a batch.

- The proximity requirement can then be realized by minimizing the amount of scheduled batches (i.e. maximizing average batch size)
- The objective is then a parametrized sum of minimizing the number of batches and losses due to unshipped cargo

Related Work

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Brandt (2017)	Build-Up Scheduling, No Batching
Emde et al. (2020)	Build-Up Scheduling, Predefined Batches

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New concepts

- Workstation groups
- Dynamic Batches
- Interdependent break-down and build-up scheduling

BSP is not a Pure Scheduling Problem

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Break-Down	Cumulative Scheduling
Build-Up	(Parallel) Cumulative Scheduling
Interdependence	Network Flow

A Multi-Commodity Network Design Model

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A Time-Expanded Network Design Model

- Inbound ULDs as sources,outbound flights as sinks
- Outbound flights are commodities
- Batch and break-down decisions are (multi)arcs that can be turned off via design variables
- Cargo flows from break-down decisions via storage nodes to batch decisions
- Cargo can flow along penalized arcs for unscheduled cargo

A Multi-Commodity Network Design Model

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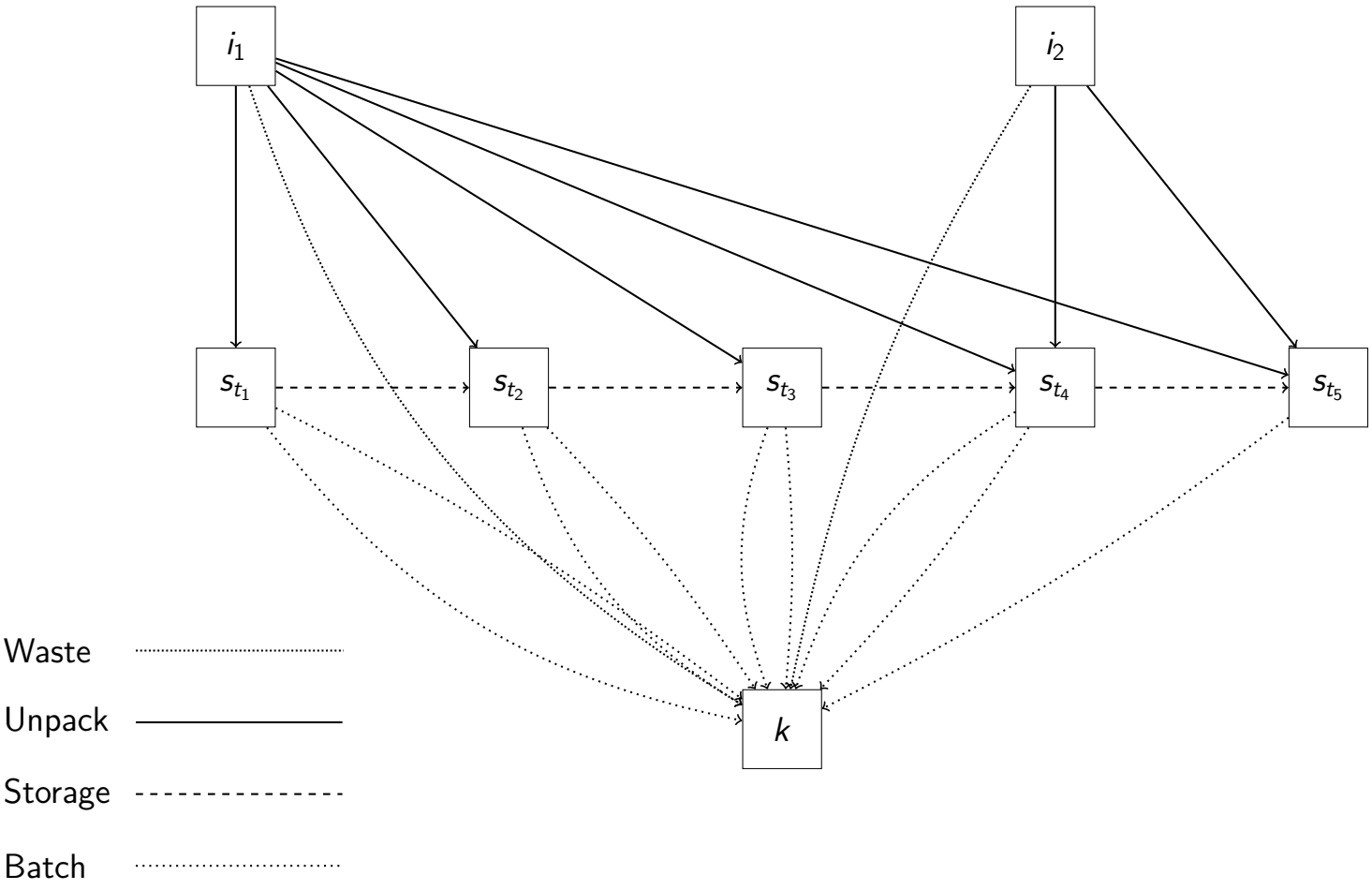

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Arc Activity

- Consider two batch candidates that differ only in the number of constructed ULD
- their respective columns in the MIP formulation will be duplicate up multiplicity
- $\rightarrow$ redefine batch decisions to be four-tuples of flight, type, workstation group and time
- introduce activity variables alongside the design variables

A MCND Model with Arc Activity

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$$
\begin{aligned}
\min \quad & \textstyle\sum_{a\in\mathcal{A}} w_a x_a + \sum_{k\in K}\sum_{a\in A} w_a^k f_a^k && && && (1)\\
\text{s.t} \quad & \textstyle\sum_{k\in K} d_k f_a^k && \leq c_a && \forall a \in A\backslash\mathcal{A} && (2)\\
& \textstyle\sum_{k\in K} d_k f_a^k && \leq c_a y_a && \forall a \in \mathcal{A} && (3)\\
& \textstyle\sum_{a\in\delta^+(v)} f_a^k - \sum_{a\in\delta^-(v)} f_a^k && = \gamma_v^k && \forall k \in K\, \forall v \in V && (4)\\
& f_a^k && \leq x_a && \forall k \in K\, \forall a \in \mathcal{A} && (5)\\
& \textstyle\sum_{a\in\mathcal{A}} \alpha_a^r y_a && \leq L^r && \forall r \in R && (6)\\
& y_a && \leq M_a x_a && \forall a \in \mathcal{A} && (7)\\
& x_a && \in \{0,1\} && \forall a \in \mathcal{A} && (8)\\
& y_a && \in [0, M_a] \cap \mathbb{Z} && \forall a \in \mathcal{A} && (9)\\
& f_a^k && \in [0,1] && \forall a \in A\, \forall k \in K. && (10)
\end{aligned}
$$

Computational Study

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Data Set

- 28 instances based ACLPP data set from Brandt (2017)
- time horizon: single day to whole week
- real shipments but randomly mapped on flight schedule
- workstation (12,24,48 ws, groups of 6) modelled with industry partner
- work in progress: no break-down scheduling

Independent variables

- Offload penalties for pre-planned ULD (*on*/*off*)
- Usable space inside ULDs (*66%*, *90%*)
- Activity formulation (*Activ*), no batch prices (*Free*), enumerated batches (*Enum*)

Setup

- 2 hours runtime
- Standard Solver (Gurobi)

Computational Study

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	Free	Enum	Activ
opt (of 336)	264	140	140
run time (s)	1604	4327	4535
gap (%)	.69	4.82	2.51

Results

- Dynamic batching complicates the problem
- Activity-base formulation provides better gap but slightly worse run times

Computational Study: Computation Results

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			Free			Enum			Activ		
#WS	Off	Cap	Opt	Gap	t	Opt	Gap	t	Opt	Gap	t
12ws	▪	66	1	2.16	6943.85	0	13.12	7205.23	0	4.78	7201.80
24ws	▪	66	28	0.00	13.31	28	0.00	156.96	25	0.01	2229.53
48ws	▪	66	28	0.00	22.97	28	0.00	152.62	28	0.00	1501.74
12ws	▪	90	4	1.83	6174.67	0	13.17	7206.93	0	5.84	7202.44
24ws	▪	90	28	0.00	58.55	28	0.00	151.91	28	0.00	137.02
48ws	▪	90	28	0.00	202.59	28	0.00	129.86	28	0.00	117.86
12ws	▫	66	7	4.29	5405.67	3	12.65	6447.57	3	7.28	6511.30
24ws	▫	66	28	0.00	8.85	5	0.04	5926.12	8	0.03	5468.70
48ws	▫	66	28	0.00	15.27	5	0.07	6011.70	7	0.05	5644.11
12ws	▫	90	28	0.00	204.73	5	15.26	6128.94	4	8.72	6255.31
24ws	▫	90	28	0.00	44.97	6	1.55	5966.61	5	1.53	5959.77
48ws	▫	90	28	0.00	147.67	4	2.02	6444.38	4	1.87	6193.93

Computational Study: Computation Results

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