European Graduate Program
Berlin - Zürich
CGC
Combinatorics

02M2 Lecture
Scheduling Stacker Cranes & Some Aspects of Logistics

Martin Grötschel

Block Course at TU Berlin
"Combinatorial Optimization at Work"

October 4 – 15, 2005

Martin Grötschel
- Institut für Mathematik, Technische Universität Berlin (TUB)
- DFG-Forschungszentrum "Mathematik für Schlüsseltechnologien" (MATHEON)
- Konrad-Zuse-Zentrum für Informationstechnik Berlin (ZIB)

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Contents

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Siemens Werk für Arbeitsplatzsysteme Siemens/Nixdorf in Augsburg

Logo Siemens Nixdorf

Die mit Siemens verbundene, aber eigenständige Siemens-Nixdorf Informationssysteme AG (SNI), die 1989 durch den Verkauf von Nixdorf an Siemens entstand, war der größte europäische Anbieter von Computerlösungen z.B. von:

a.)
Großrechner (Systemfamilie 7500) und Supercomputern (VPP500),

b.)
Minicomputern / Mehrplatzsystemen (etwa: MX- und RM - Serie, Targon, 8860/8862/BNC),

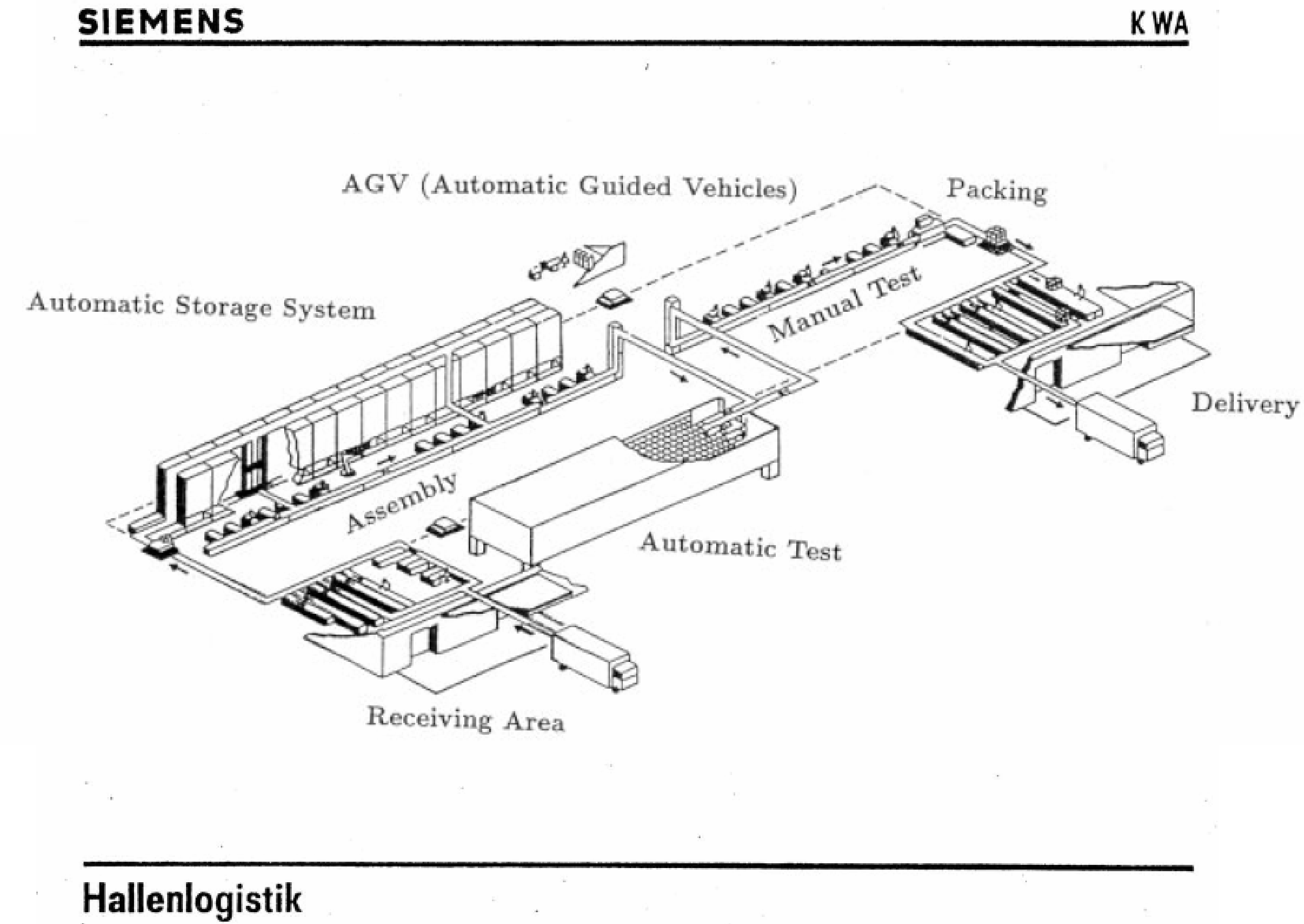
c.)
Personalcomputern (z.B. Scenic),

d.)
Software, Beratung und Trainig für alle Systeme.

Siemens-Nixdorf wurde 1999 an die amerikanischen Großinvestoren Kohlberg Kravis Roberts verkauft und in "Wincor Nixdorf" umbenannt.

Wincor Nixdorf ist nach eigenen Angaben als Anbieter von IT-Lösungen und Dienstleistungen für Handel und Banken Marktführer in Deutschland.

Principal Layout of the Factory



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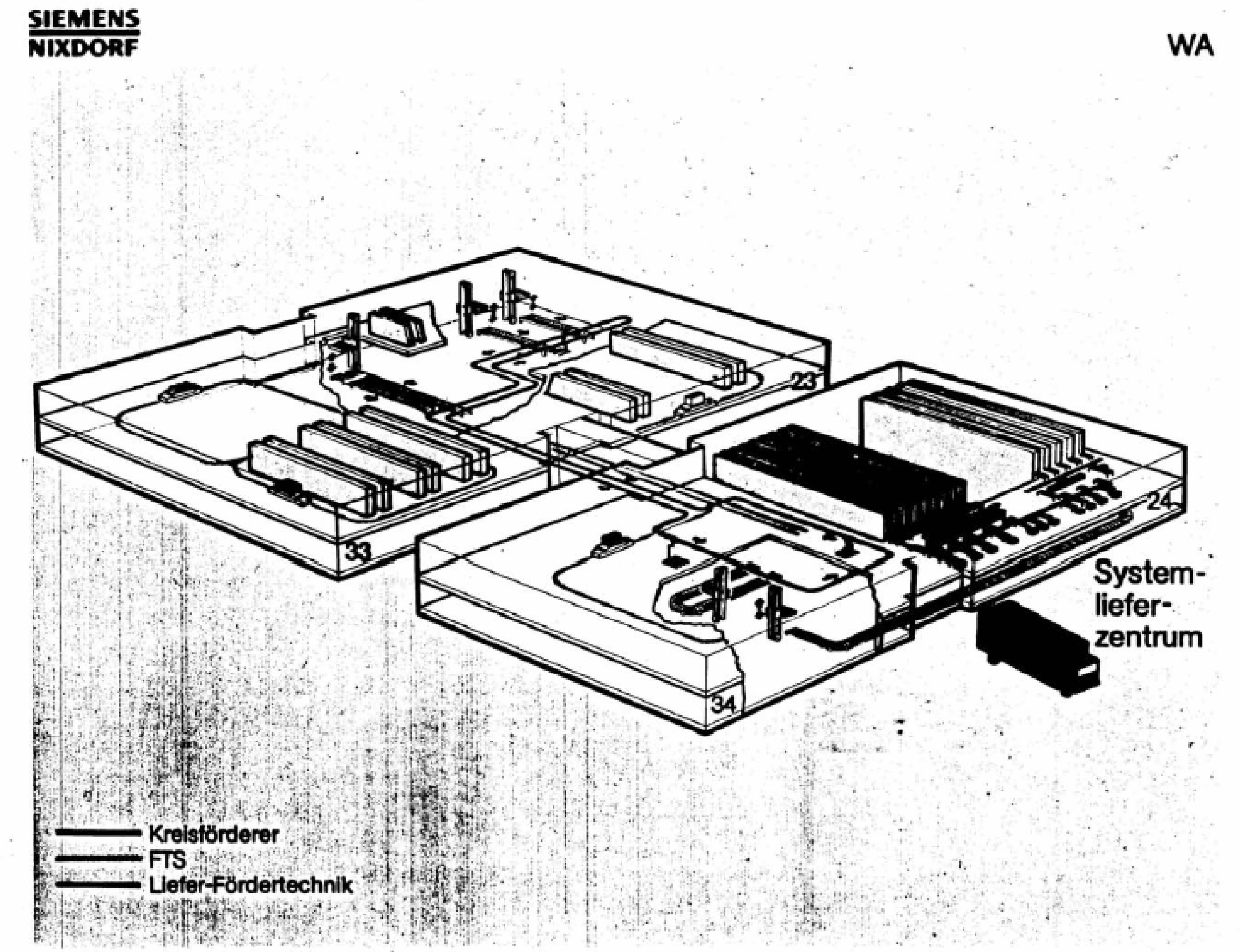
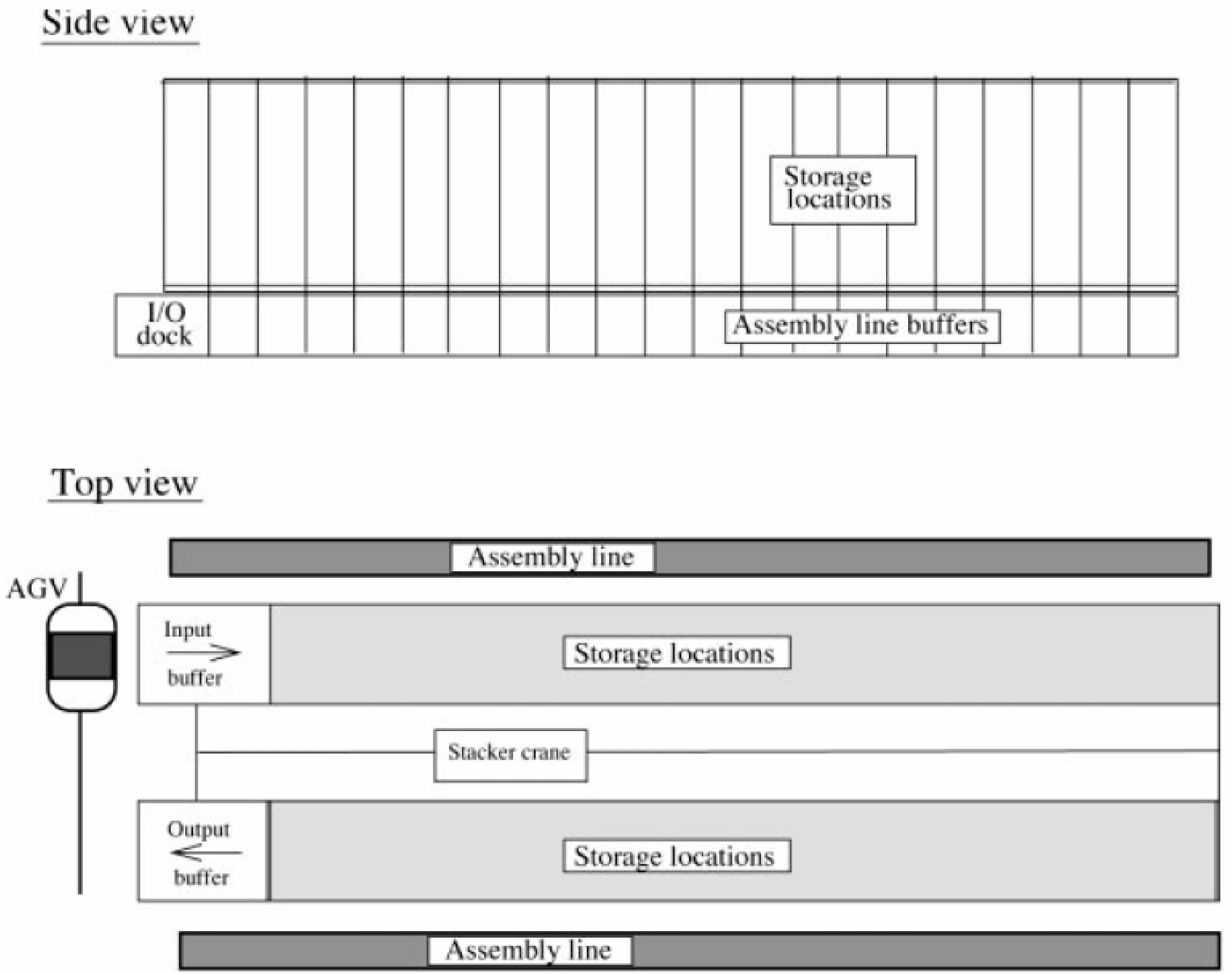
Principal Layout of the Distribution Center



Systemlieferzentrum
SLZ-Fördertechnik

The Warehouse Layout



Simulating Reality

- Simulating the stacker crane
- Simulating the factory logistics
- Simulation languages?

Possible sources of trouble:

- Who has designed the factory?
- What is the role of the planning department?

AMSEL

Konrad-Zuse-Zentrum für Informationstechnik Berlin

Division Scientific Computing

Department Optimization

AMSEL
A Modelling and Simulation Environment Library

Version
1.6

Authors
Norbert Ascheuer *(AMSEL Callable Library)*
Bärbel Pöhle *(ZGUI - AMSEL Graphical User Interface)*

- Click here to get your registered copy of AMSEL.
- AMSEL-Homepage (Further information on AMSEL, Online documentation, etc.)

Simulation

Computational results – Simulation Tool

— implemented in C on a Siemens PC–MX2 (NSC 32016).

— tested with real-life data.

Simulation of a one-week long real production run of a stacker crane using AMSEL

	øRL	øSim	øDev	max Dev	% Dev	# Ev	Time
1	76.27	76.83	2.42	20	0.73	2955	40.42
2	75.45	76.34	1.96	11	1.17	2993	40.46
3	78.81	78.95	2.01	9	0.18	2937	40.00
4	76.19	76.58	2.09	9	0.51	2855	39.72
5	77.11	76.73	2.06	20	0.49	3220	41.82

Table 1: Validation of the simulation modell

øRL : average travel time in real life (in sec.)
øSim : average travel time in simulation (in sec.)
øDev : average deviation between the first two values (in sec.)
max Dev : maximal deviation between the first two values (in sec.)
% Dev : deviation between real life and simulation in % (| øRL - øSim |) / øSim
# Ev : Number of events in the simulation for two shifts
Time : CPU-Computing Time (in sec.)

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Optimization

A preview of some results

Computational results – Optimization tool

	# TT	uTr–P	uTr–O	I %	max-TT	ø# TT
1	416	8599	8325	3.18	6	2.31
2	421	8655	8141	5.93	8	1.94
3	405	8238	7956	3.42	6	2.27
4	398	8017	7634	4.77	8	1.93
5	447	9411	8951	4.88	8	2.13

Table 2 : Minimizing the unloaded travel time
(normal conditions)

# TT	:	number of transportation tasks (TT)
uTr–P	:	unloaded travel time with priorities (in sec.)
uTr–O	:	unloaded travel time with optimization (in sec.)
V %	:	improvement in % (((uTr–P) - (uTr–O)) / (uTr–P))
max-TT	:	maximal number of TT to be handled once in a time
ø# TT	:	average number of TT to be handled once in a time

Contents

Herlitz at Falkensee (Berlin)

Herlitz at Falkensee (Berlin)

Built in the early nineties for ~200 mio Euro

Herlitz Homepage, October 2005

Herlitz PBS AG

Products and services for an intelligent management of goods

Berlin. The Herlitz PBS AG as one of the best-known German traditional companies has a yearly turnover of 347 million Euro (2003) and thus, belongs to the leading producers of paper, office supplies and stationary (PBS) in Europe. In Eastern Europe Herlitz even today is the market leader. Place of Herlitz' business headquarters is Berlin-Tegel.
Employing a staff of about 3000 in Germany and Europe the Herlitz PBS AG as the first German company in the year 2002 was able to successfully conculde insolvency proceedings from its own strength and thus, set the course for the future.
Herlitz has been a public limited company quoted at the stock exchange since 1977, 67 per cent of which belong to the banks. The remaining share are widespread shareholdings.

Headquarters Herlitz Berlin-Tegel

Logistics center Falkensee

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Stacker crane

Warehouse shelf

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Stacker crane

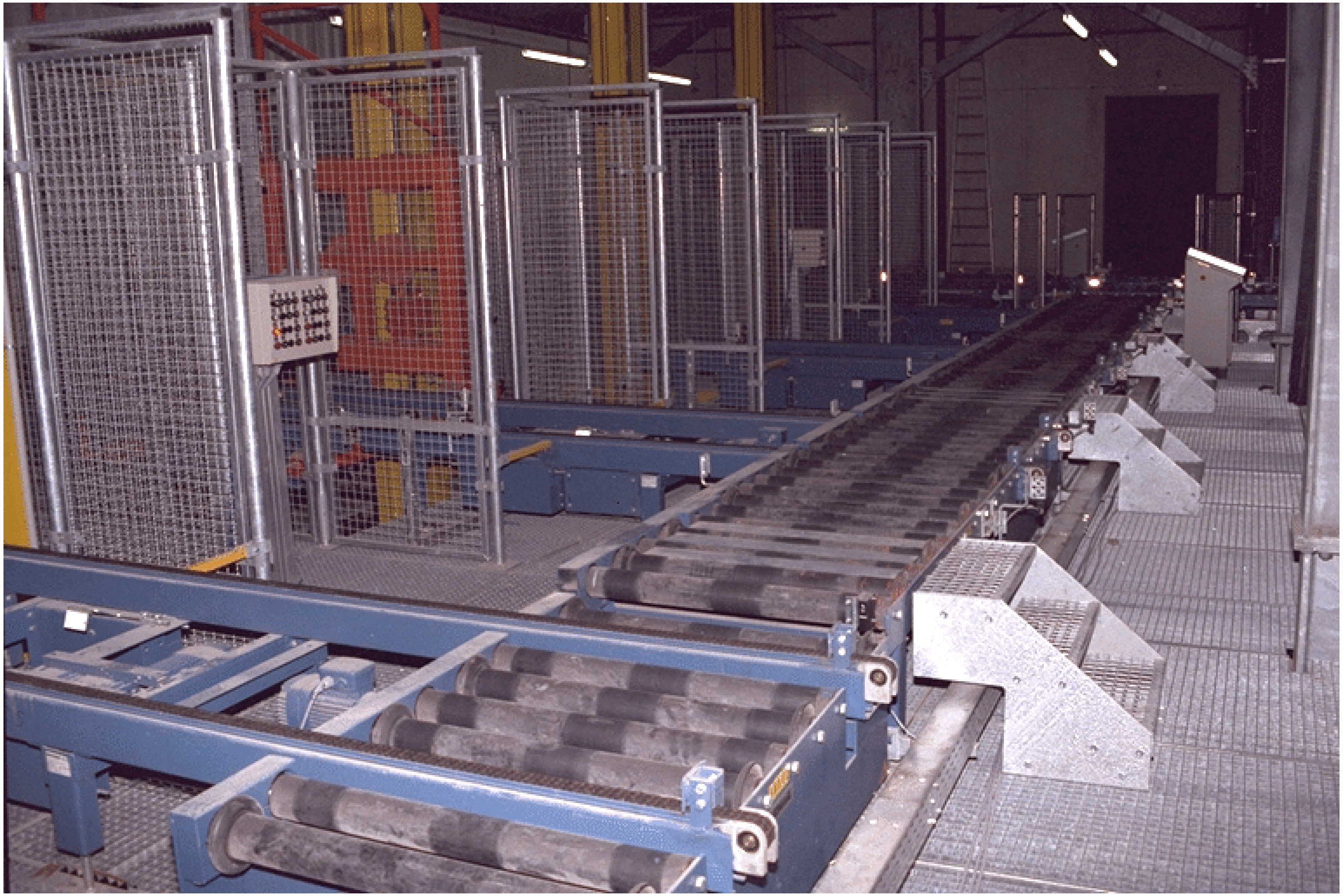
Stacker crane

Control of the stacker cranes in a Herlitz warehouse

Horizontal transport

Horizontal transport / elevators

Horizontal transport / elevators



Wrapping

Truck Loading

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Truck Loading

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innerbetriebliche Logistik

The Logistics Network in Falkensee

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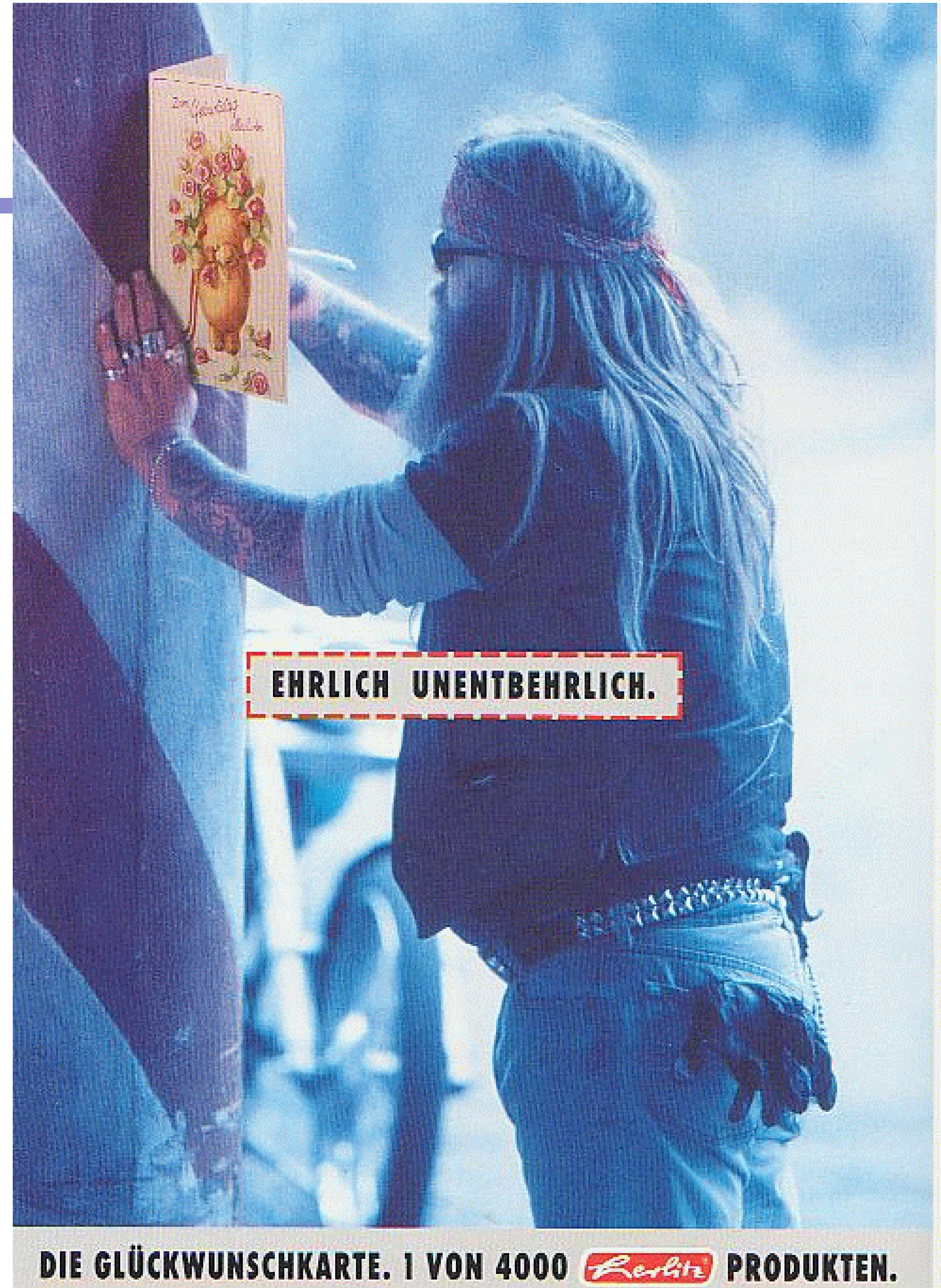
Contents

CO at Work

Greeting Cards



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Commissioning of greeting cards

- Theory
- Simulation
- Practice

- Slides

Slides

Order Picking Project:

Norbert Ascheuer, Martin Grötschel, Nicola Kamin, Jörg Rambau

Combinatorial online optimization in practice

OPTIMA, 57 (1998) 1-6

Kamin, Nicola:

On-Line Optimization of Order Picking in an Automated Warehouse

PhD Thesis, TU Berlin, 1998

Commissioning sequence

Picture deleted

Contents

Online Optimization

- There will be two special lectures on online optimization and the mathematics involved
- Now: Just a brief introduction

Echtzeit-Optimierung großer Systeme

Schwerpunktprogramm der Deutschen Forschungsgemeinschaft (DFG)

[Aktuelles] [Allgemeine Informationen] [Mailing Liste] [Liste aller Projekte] [Informationen des Koordinators] [Veranstaltungen] [Vortragskalender] [Publikationen] [Gäste] [Software] [Weitere Links] [Kritik, Anregungen?]

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- Software
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- Kritik, Anregungen ?

Aktuelles

Das Schwerpunktprogramm ist abgeschlossen.

- Wir haben einen als ausführlichen Bericht einen **Abschlußband** herausgegeben. Danke an alle Mitwirkenden für ihren Einsatz!

- Das Schwerpunktprogramm verfügt über einen **Schwerpunkt-Song**

Allgemeine Informationen zum Schwerpunkt

- Ziele des Schwerpunktsprogramms
- Mailing Liste *dfg-echtzeit*
- Koordinator
- Gutachter
- Auszüge aus dem Antrag auf Genehmigung des Schwerpunktprogramms

Liste aller Arbeitsgruppen und Projekte

- Liste aller Projekte
- Liste aller e-mail Adressen
- Liste aller Mitarbeiter

http://www.zib.de/dfg-echtzeit/

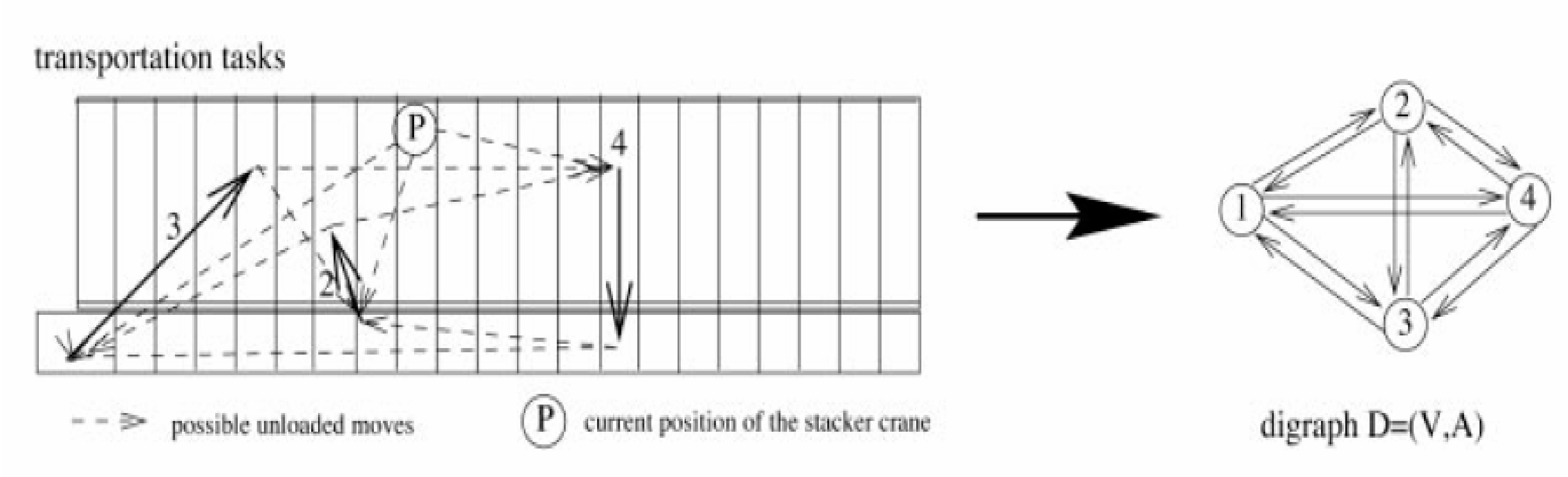
Veranstaltungen des Schwerpunkts

Contents

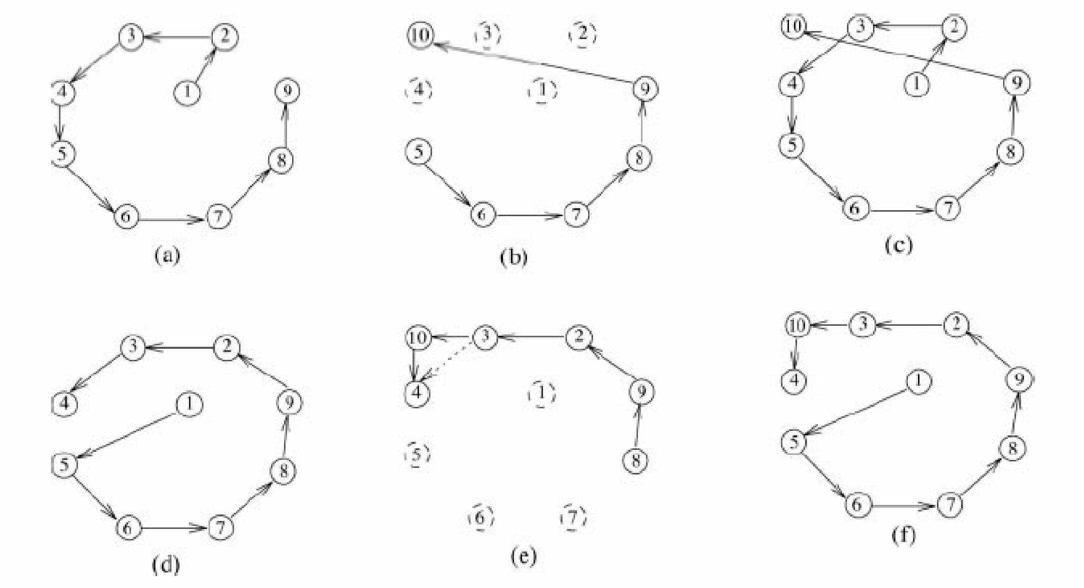
Stacker Crane "Background Problem"

- What do we have to solve when we want to "optimize" (find a good control) of the stacker cranes.

Modelling a Snapshot Problem



- Problems with this snapshot model and the replan heuristic



LP Cutting Plane Approach

Even MODELLING is not easy!

What is the „right“ LP relaxation?

N. Ascheuer, M. Fischetti, M. Grötschel, „Solving the Asymmetric Travelling Salesman Problem with time windows by branch-and-cut“, Mathematical Programming A (2001)

Model 1

$$\min c^T x$$

$$
\begin{array}{lll}
x(\delta^+(i)) & = 1 & \forall i \in V \cup \{0\} \\
x(\delta^-(i)) & = 1 & \forall i \in V \cup \{0\} \\
t_i + \vartheta_{ij} - (1 - x_{ij}) \cdot M & \leq t_j & \forall i, j \in A, j \neq 0 \\
r_i \leq \quad t_i & \leq d_i & \forall i \in V \\
t_i & \in \mathbf{N} & \forall i \in V \cup \{0\} \\
x_{ij} & \in \{0,1\} & \forall i, j \in A.
\end{array}
$$

Model 2

$$\min c^T x$$

$$x(\delta^+(i)) = 1 \qquad \forall i \in V \cup \{0\}$$

$$x(\delta^-(i)) = 1 \qquad \forall i \in V \cup \{0\}$$

$$x(A(W)) \leq |W| - 1 \qquad \forall W \subset V \cup \{0\}, 2 \leq |W| \leq n$$

$$x(P) \leq |P| - 1 = k - 2 \qquad \forall \text{infeasible path } P = (v_1, v_2, \ldots, v_k)$$

$$x_{ij} \in \{0,1\} \qquad \forall (i,j) \in A.$$

Model 3

$$\min c^T x$$

$$x(\delta^+(i)) = 1 \qquad \forall i \in V \cup \{0\}$$

$$x(\delta^-(i)) = 1 \qquad \forall i \in V \cup \{0\}$$

$$\sum_{\substack{i=1 \\ i \neq j}}^{n} y_{ij} + \sum_{\substack{i=0 \\ i \neq j}}^{n} \vartheta_{ij} \cdot x_{ij} \leq \sum_{\substack{k=1 \\ k \neq j}}^{n} y_{jk} \quad \forall j \in V$$

$$r_i \cdot x_{ij} \leq y_{ij} \leq d_i \cdot x_{ij} \qquad i, j = 0, \ldots, n, i \neq j, i \neq 0$$

$$x_{ij} \in \{0,1\} \qquad \forall (i,j) \in A$$

$$y_{ij} \in \{0,1,2,\ldots\} \qquad \forall (i,j) \in A$$

Model 1, 2, 3

$$\min c^T x$$

$x(\delta^+(i))$	$=1$	$\forall i \in V \cup \{0\}$
$x(\delta^-(i))$	$=1$	$\forall i \in V \cup \{0\}$
$t_i + \vartheta_{ij} - (1 - x_{ij}) \cdot M$	$\leq t_j$	$\forall i, j \in A, j \neq 0$
$r_i \leq \quad t_i$	$\leq d_i$	$\forall i \in V$
t_i	$\in \mathbf{N}$	$\forall i \in V \cup \{0\}$
x_{ij}	$\in \{0,1\}$	$\forall i, j \in A.$

$$\min c^T x$$

$x(\delta^+(i))$	$=1$	$\forall i \in V \cup \{0\}$
$x(\delta^-(i))$	$=1$	$\forall i \in V \cup \{0\}$
$\sum_{\substack{i=1 \\ i \neq j}}^{n} y_{ij} + \sum_{\substack{i=0 \\ i \neq j}}^{n} \vartheta_{ij} \cdot x_{ij}$	$\leq \sum_{\substack{k=1 \\ k \neq j}}^{n} y_{jk}$	$\forall j \in V$
$r_i \cdot x_{ij} \leq y_{ij} \leq d_i \cdot x_{ij}$		$i, j = 0, \ldots, n, i \neq j, i \neq 0$
x_{ij}	$\in \{0,1\}$	$\forall (i, j) \in A$
y_{ij}	$\in \{0,1,2,\ldots\}$	$\forall (i, j) \in A$

$$\min c^T x$$

$x(\delta^+(i))$	$=1$	$\forall i \in V \cup \{0\}$
$x(\delta^-(i))$	$=1$	$\forall i \in V \cup \{0\}$
$x(A(W)) \leq \|W\| - 1$		$\forall W \subset V \cup \{0\}, 2 \leq \|W\| \leq n$
$x(P) \leq \|P\| - 1 = k - 2$		$\forall$ infeasible path $P = (v_1, v_2, \ldots, v_k)$
$x_{ij} \in \{0,1\}$		$\forall (i, j) \in A.$

Cutting Planes Used for all Three Models (Separation Routines)

- Subtour Elimination Constraints (SEC)
- 2-Matching Constraints
- -Inequalities
- "Special" Inequalities and PCB-Inequalities
- D_k-Inequalities
- Infeasible Path Elimination Constraints (IPEC)
- Strengthened -Inequalities
- Two-Job Cuts
- Pool Separation
- SD-Inequalities
- \+ various strengthenings/liftings

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Further Implementation Details

- Preprocessing
  - Tightening Time Windows
  - Release and Due Date Adjustment
  - Construction of Precedences
  - Elimination of Arcs
- Branching (only on x-variables)
- Enumeration Strategy (DFS, Best-FS)
- Pricing Frequency (every 5th iteration)
- Tailing Off
- LP-exploitation Heuristics
  (after a new feasible LP solution is found),

  they outperform the other heuristics

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1. Stacker cranes and logistics at a Siemens plant
2. The Herlitz logistics center in Falkensee
3. A special topic: Order picking (greeting cards)
4. Online problems in combinatorial optimization
5. Stacker crane optimization: Modelling issues
6. Solutions

CO at Work

Math Meth Oper Res (1999) 49 : 501–515

Mathematical Methods
of Operations Research

Order picking in an automatic warehouse: Solving online asymmetric TSPs

Norbert Ascheuer, Martin Grötschel, Atef Abdel-Aziz Abdel-Hamid

Konrad-Zuse-Zentrum für Informationstechnik Berlin (ZIB), Takustr. 7, D-14195 Berlin-Dahlem, Germany (e-mail: ascheuer@zib.de)

Abstract. We report on a joint project with industry that had the aim to sequence transportation requests within an automatic storage system in such a way that the overall travel time is minimized. The manufacturing environment is such that scheduling decisions have to be made before all jobs are known. We have modeled this task as an *online* Asymmetric Traveling Salesman Problem (ATSP). Several heuristics for the online ATSP are compared computationally within a simulation environment to judge which should be used in practice. Compared to the priority rule used so far, the optimization package reduced the unloaded travel time by about 40%. Because of these significant savings our procedure was implemented as part of the control software for the stacker cranes of the storage systems.

Key words: Traveling Salesman Problem, online-algorithm, automatic storage system

Simulation

Simulation of a one-week long real production run by AMSEL

Computational results – Simulation Tool

— implemented in C on a Siemens PC–MX2 (NSC 32016).

— tested with real-life data.

	øRL	øSim	øDev	max Dev	% Dev	# Ev	Time
1	76.27	76.83	2.42	20	0.73	2955	40.42
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3	78.81	78.95	2.01	9	0.18	2937	40.00
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Table 1: Validation of the simulation modell

øRL : average travel time in real life (in sec.)
øSim : average travel time in simulation (in sec.)
øDev : average deviation between the first two values (in sec.)
max Dev : maximal deviation between the first two values (in sec.)
% Dev : deviation between real life and simulation in %
(| øRL - øSim |) / øSim
Ev : Number of events in the simulation for two shifts
Time : CPU-Computing Time (in sec.)

Testing Heuristics

priority:	SNI-priority rule.
random:	Generation of random sequences.
optimal:	Each subproblem is solved to optimality using the branch&bound code by Fischetti and Toth [11].
greedy:	Greedy heuristic.
greedy + 2opt:	Greedy heuristic with additional improvement heuristic (2-opt heuristic).
greedy + 3opt:	Greedy heuristic with additional improvement heuristic (3-opt heuristic).
fit-in:	The newly generated task is inserted in the best possible way into the existing sequence.
farins:	Farthest insertion heuristic.
listins:	List insertion heuristic: The nodes to be inserted in the best possible way are taken in the order $1, 2, \ldots, n$.
randins:	Random insertion heuristic: The nodes to be inserted in the best possible way are chosen randomly.
bestins:	Best insertion heuristic: Choose always the best possible insertion.
shuffle:	Shuffle heuristic: Start with sequences of length 1, "shuffle" them together to sequences of length 2, "shuffle" these together to sequences of length 4, etc.

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Results of Heuristics

Table 3.8. Average unloaded travel-time (in sec)

HEURISTIC	1	2	3	4	5	∑
priority	17.31	19.18	19.35	17.72	19.96	93.52
random	19.50	18.36	17.83	17.10	19.84	92.63
optimal	11.04	**14.54**	**11.10**	**9.29**	13.09	59.06
bestins	11.16	14.66	11.86	12.53	12.58	62.79
shuffle	11.82	15.38	11.28	10.76	13.80	63.04
greedy	11.82	15.42	12.04	11.63	**12.20**	63.11
greedy + 3opt	11.51	15.32	12.02	11.51	12.76	63.12
listins	12.73	15.14	11.88	10.98	12.80	63.53
greedy + 2opt	11.33	15.34	12.10	12.25	12.62	63.64
randins	**10.84**	15.44	11.71	11.77	14.11	63.87
farins	12.45	15.10	13.52	10.53	14.00	65.60
fit-in	14.81	17.72	17.62	13.19	17.27	80.61
improvement	37.4%	24.2%	42.6%	47.6%	38.9%	36.8%

Poor optimization results

Computational results – Optimization tool

	# TT	uTr–P	uTr–O	I %	max-TT	ø# TT
1	416	8599	8325	3.18	6	2.31
2	421	8655	8141	5.93	8	1.94
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Table 2 : Minimizing the unloaded travel time
(normal conditions)

# TT	:	number of transportation tasks (TT)
uTr–P	:	unloaded travel time with priorities (in sec.)
uTr–O	:	unloaded travel time with optimization (in sec.)
V %	:	improvement in % (((uTr–P) - (uTr–O)) / (uTr–P))
max-TT	:	maximal number of TT to be handled once in a time
ø# TT	:	average number of TT to be handled once in a time

Final decision

Based on the studies presented in this paper we designed and implemented an *optimization package* which aims at minimizing the travel time of a stacker crane. As the stacker crane should never wait until the optimization program finishes its calculation we decided to implement a 3-phase process:

Phase 1: Perform cheapest insertion of the new order (*fit-in*).

Phase 2: Run an iterative cheapest insertion on a random ordering of the current order pool. Then choose the best sequence of Phase 1 and 2 (*randins*).

Phase 3: Solve the ATSP with the current transportation tasks to optimality and replace the old sequence by the optimal one (*optimal*).

Optimized Stacker Crane

	# TT	uTr–P	uTR–O	I %
1	18	344	239	30.52
2	10	194	143	26.28
3	18	347	211	39.19
4	26	507	330	34.91
5	20	388	283	27.06

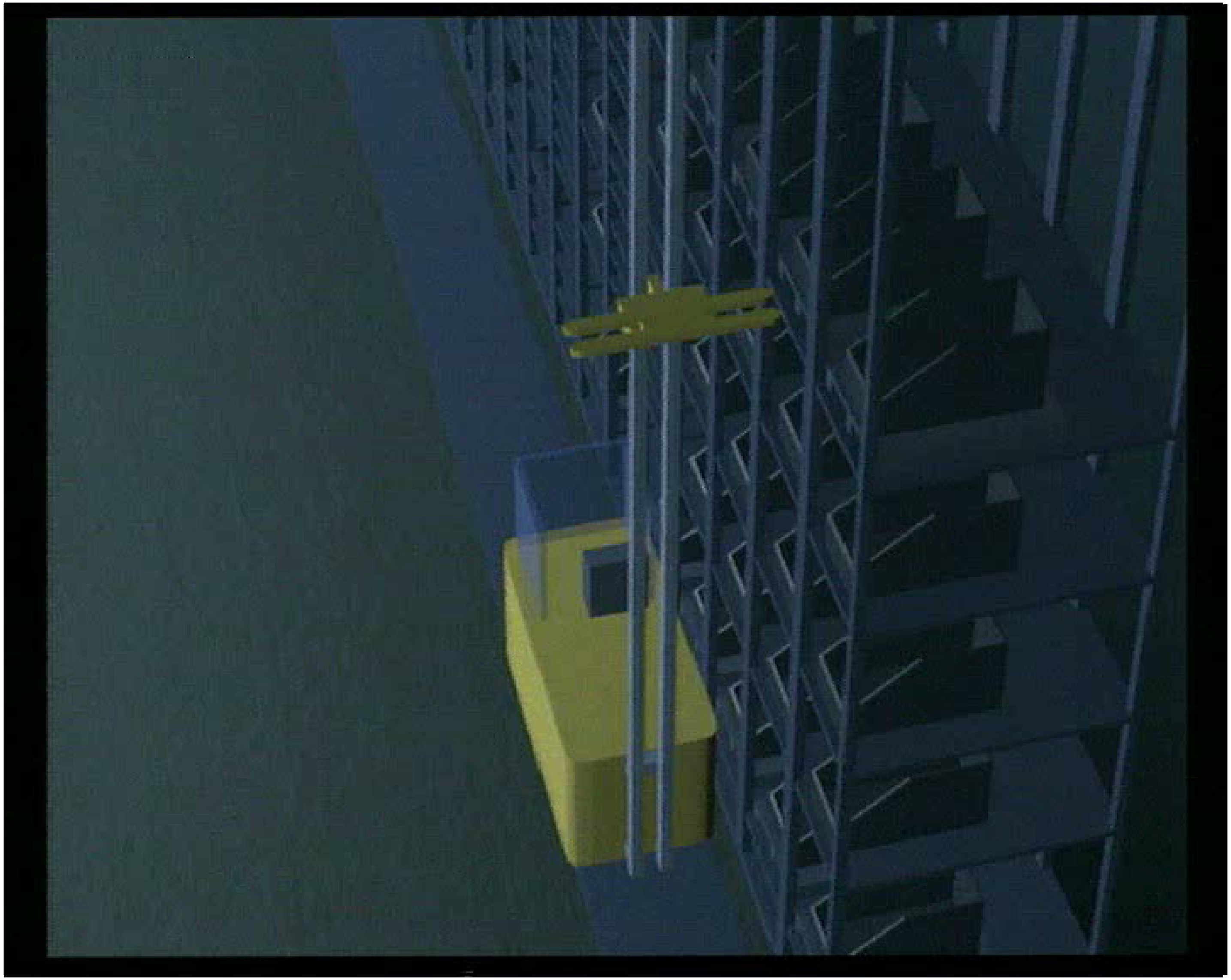
Table 3 : Minimizing the unloaded travel time
(heavy load conditions -- artificial breakdown)

D	# TT	uTr–P	uTr–O	I %	max-TT	ø#TT	Plus
1	50	917	693	24.42	29	13.32	3
2	49	974	749	23.10	20	8.32	0
3	50	1007	783	22.24	26	12.23	3
4	49	889	662	25.53	31	15.24	3
5	50	985	839	14.82	25	13.08	1

Table 4 : Minimizing the unloaded travel time
(heavy load conditions – artificial breakdown)

TT : number of transportation tasks (TT)
uTr–P : unloaded travel time with priorities (in sec.)
uTr–O : unloaded travel time with optimization (in sec.)
V % : improvement in % (((uTr–P) · (uTr–O)) / (uTr–P))
max-TT : maximal number of TT to be handled once in a time
ø# TT : average number of TT to be handled once in a time
Plus : number of additional TT to be handled
in a given time period.

Optimizing the stacker cranes of a Siemens-Nixdorf warehouse



Results of the „model competition“

- Very uneven performance
- Model 1 is really bad in general
- Model 2 is best on the average (winner in 16 of 22 test cases)
- Model 3 is better when few time windows are active (6 times winner, last in all other cases, severe numerical problems, very difficult LPs)

How could you have guessed?

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Unevenness of Computational Results

problem	#nodes	gap	#cutting planes	#LPs	time
rbg041a	43	9.16%	> 1 mio	109,402	> 5 h
rbg067a	69	0%	176	2	6 sec

Largest problem solved to optimality: 127 nodes
Largest problem not solved optimally: 43 nodes

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European Graduate Program Berlin - Zürich CGC Combinatorics

02M2 Lecture

Scheduling Stacker Cranes & Some Aspects of Logistics

The End

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