Integrated Facilities Design

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Overview

- *Facilities Design Problem*
- *Sequential Facilities Design Framework*
- *Concurrent design of conceptual block layout and I/O point location*
- *Conclusions and research directions*

Facilities Design Problem

- Conceptual design of physical enclosure and infrastructure for a (manufacturing or service) system
- Objective = minimize the after-tax NPC (net present cost) of the facility, equipment, and material handling operations
- Difficult problem
- Research and practice disconnected

Facilities Design Decisions

- Research focuses on highly synthesized problems
- For types of decisions
  - Building size and shape
  - Conceptual block layout
  - Location of I/O points
  - Material flow network

Systematic Layout Planning (SLP) Design Framework

- Muther (1961,1973) to block layout
- Successive increase in level of detail
- Extensions to detailed, material handling layout
- Sequential approach

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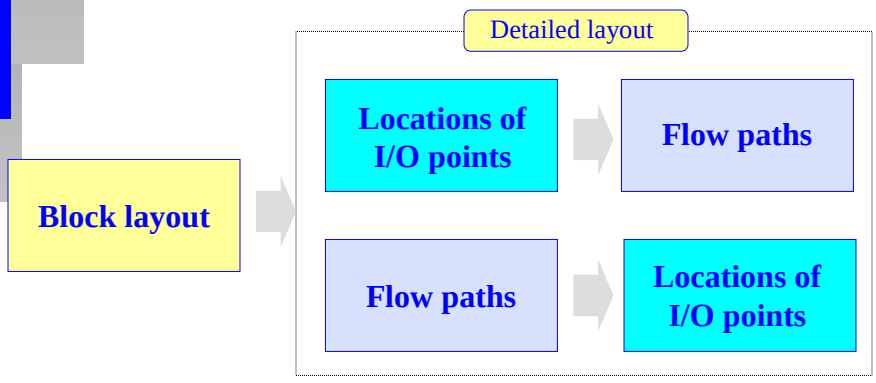
Extended SLP Design Framework

- Detailed material handling layout
  - I/O points and aisles



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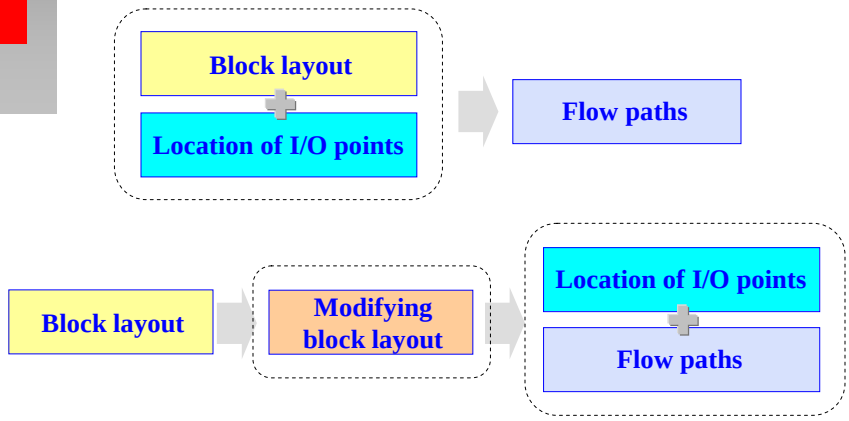
Facilities Design Framework with Integrated Steps

- Different combinations of steps



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Concurrent Block Layout and I/O Point Location Problem (CLIOPS)

- Problem definition
- Block layout representation
- LP model for block layout and I/O point location with rectilinear distance
- Relocation of I/O points with contour distance
- Simulated annealing layout algorithm
- Computational results

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CLIOPS Description

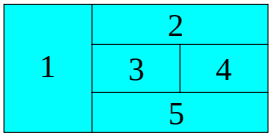
- Objective = minimize total travel (TT) between I/O points with contour dist.
- Constraints
  - One I and O point per department located on contour
  - Rectangular departments
  - Department areas and shapes bounds
  - Contour distance metric (boundaries)
  - Given building floor

Block Layout Representation and Model

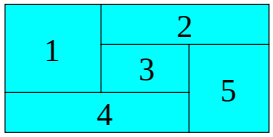
- Rectilinear distance metric and area constraint I/O point location
- Sequence Pair
  - Slicing and non-slicing
- Area lower bounding supports

Sequence Pair Block Layout Representation

- *Two ordered sets*
  - *Murata (1996) for IC design*
  - *Slicing and non-slicing*
  - *Penalty for violating floor area*



$\Gamma^+ = (1, 2, 3, 4, 5)$
$\Gamma^- = (1, 5, 3, 4, 2)$



$\Gamma^+ = (1, 2, 3, 4, 5)$
$\Gamma^- = (4, 1, 3, 5, 2)$

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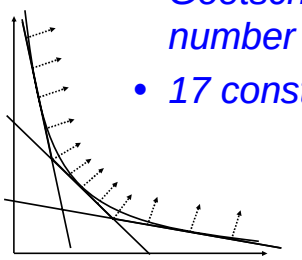
Area Constraint Linearization

- *Required department area is quadratic constraint*
- *Polyhedral outer approximation*
  - *Goetschalckx (1998) a priori fixed number*
  - *17 constraints with equal angle sectors*



$$\tan\left(\frac{\pi}{17}\right)(x_i^r - x_i^l) + \tan\left(\frac{\pi}{17}\right)(y_i^t - y_i^b) \geq 2a_i$$

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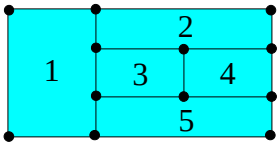
I/O Point Relocation Problem



- Shortest path distance metric over department boundaries (contour)
- B&B Optimal Algorithm
  - Kim and Kim (1999)
  - Requires to much computing time
- Three heuristics

I/O Point Relocation Heuristics

- Initial Location
  - Closest position
- Three Improvement Heuristics
  - Sequential Improvement Method (SIM): move seq. each point to better position
  - Iterative Improvement Method (IIM): move all input then output points, iterate
  - Extended Iterative Improvement Method (EIIM): IIM plus move one point randomly

Relocation Heuristics Performance

	Average Optimality gap (%)	Average CPU time (s)
Optimal	-	0.393
Initial	2.91	-
SIM	0.056	0.0005
IIM	0.047	0.0001
EIIM	0.001	0.0002

PC 700 Mhz, 20 test problems, 20 departments

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Simulated Annealing Algorithm

- Modifies sequence pairs
  - Four neighborhood moves
    - Swap department indices
    - Insert department indices
  - Solve LP and use a relocation heuristic
- Evaluate layout
  - Contour TT + floor boundary penalty + department area penalty

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Computational Experiment: CLIOPS versus Sequential

- *Int_KG: as described above*
- *Seq_KK: SA for block layout + B&B for I/O point location*
- *Seq_TS: GA for block layout + B&B for I/O point location*
- *Same time limit (set by Int_KG)*
- *10 replications*
- *Shape factor [2.5, 4.0] or problem def.*

Effectiveness Comparison CLIOPS vs. Sequential Algorithms

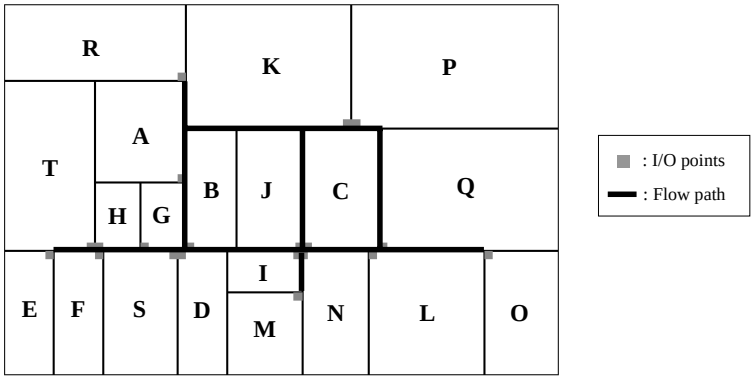
Problem	Algorithm								
	INTE-KG			SEQ-KK			SEQ-TS		
	min	avg	std	min	avg	std	min	avg	std
10_Van Camp	6461.4	8439.2	1423.1	11627.1	14726.6	2267.6	9530.5	17222.7	2702.8
20_Armour and Buffa	2699.9	3018.7	121.5	3044.4	3501.3	324.1	3457.5	3593.2	104.5
10_random	976.19	1042.1	62.4	1241.3	1332.4	168.7	infeasibleÜ		
15_random	1961.7	2233.6	187.3	2737.8	2872.3	255.9	2945.2	3065.5	39.2
20_random	8209.1	9192.1	685.1	9093.5	10302.0	622.8	9535.3	10256.7	851.7
30_radom	28376.9	29606.3	1005.1	29295.9	30403.1	736.9	31803.9	33221.7	972.7
40_random	68430.0	70119.8	1140.5	69188.8	70641.8	1025.6	79006.2	83045.5	2296.4

ÜSEQ_TS did not find a feasible layout for 10_random.

Relative Performance: CLIOPS versus Sequential

Problem	Algorithm						Average CPU time (s)
	CLIOPS		Seq_KK		Seq_TS		
	min.	avg.	min.	avg.	min.	avg.	
10_Van_Camp	0	0	80	75	45	104	40
20_Armour_Buffa	0	0	13	16	28	19	727
10_random	0	0	27	28			65
15_random	0	0	40	29	50	37	271
20_random	0	0	11	12	16	12	852
30_random	0	0	3	3	12	12	3766
40_random	0	0	1	1	15	18	15622

Armour and Buffa Problem (1963): 20 Departments



TT = 2700

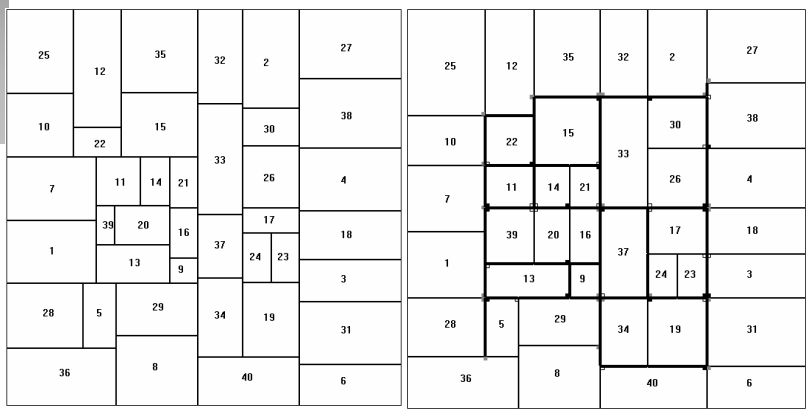
Numerical Experiment Conclusions

- CLIOPS is significantly more effective, especially for smaller problems
- Contour travel smaller than rectilinear centroid-to-centroid
- Symmetrical relationships co-locate input and output points
- Acceptable running times

Conclusions

- Synthesized problems yield real-world infeasible solutions
  - Shape constraints & contour distance
- Combination of steps in design algorithms yields significant reduced costs
- Future research on creating more feasible designs

Layout Comparison for the 40_random Problem



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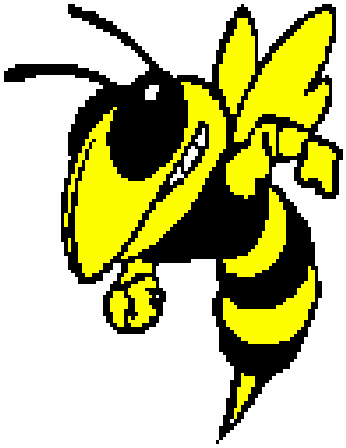
Thank You
Can I Answer Any Questions?



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