Optimize Earthwork Hauling Plan with Minimum Cost Flow Network

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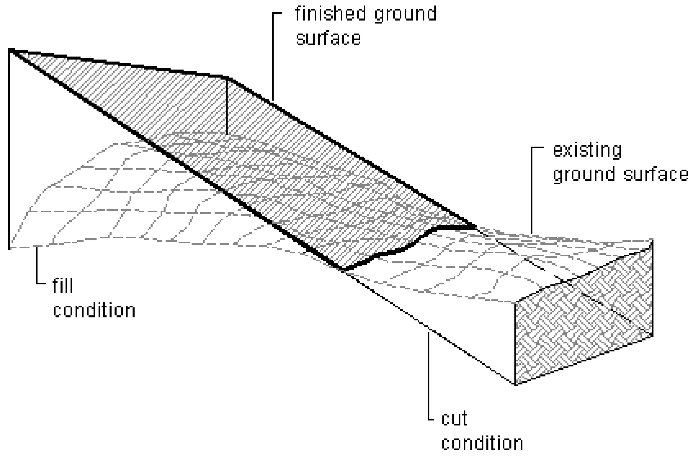
Outline

- Background
- Minimum Cost Flow Based Method
- Case Study & Validation
- Conclusion

Background



Site grading design completed

- **Cut fill balance**
- **Quantity takeoff**

Major tasks in earthwork planning:

- **Material Earthwork Allocation**
- **Temporary haul road design**
- **Equipment Fleet optimization**

Background

Earthwork allocation:
Find the most economic combination of haul jobs to move the material from section to section

1 37133	4 14846	7 5013	10 1065	13 -7288	16 -9169	19 -2661	22 16089
2 24797	5 4497	8 -17920	11 -26853	14 -27369	17 -21327	20 -4500	23 11153
3 21111	5 3339	9 -4915	12 -8243	15 -8123	18 -8382	21 -3025	24 10732

Job	Cut	Fill	Volume (bcm)	Route
Job-A	20	19	8100	-
Job-B	20	18	16700	[19]
Job-C	21	18	5500	[20, 19,17]
Job-D	21	17	4400	[20, 19, 18]
Job-E	33	17	18600	[21, 20, 19, 18]
Job-F	33	16	36000	[21, 20, 19, 18, 17]
Job-G	33	15	8400	[21, 20, 19, 18, 17, 16]

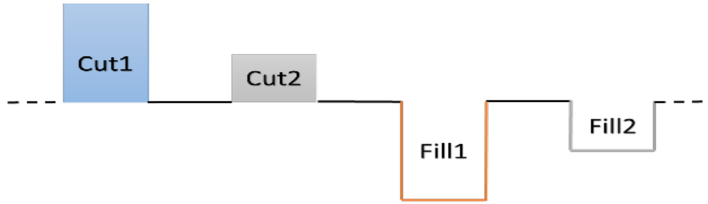
Problem

Limitations of earthwork allocation optimization by linear programming

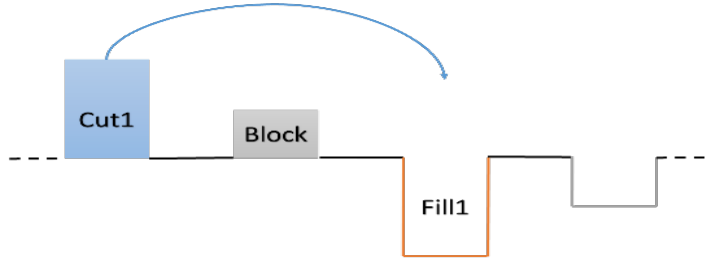
1) Time consuming to establish and solve equations
2) Generate Haul jobs with conflicts:

   Hard blocks: Can be identified before hand, but cannot be eliminated.

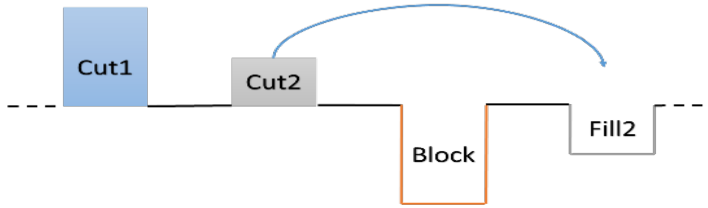
   Soft blocks: Embedded within haul jobs, can be eliminated.
3) Cannot provide job sequence



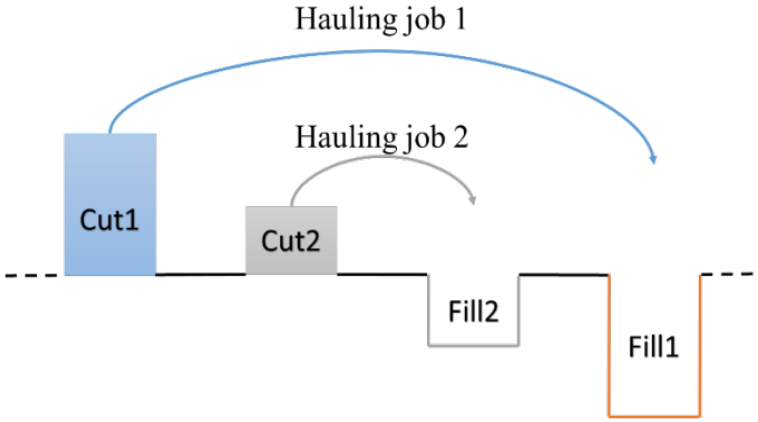
(a) Cut/fill layout



(b) Hauling job 1



(c) Hauling job 2



Simulation Methods

Construction Operations Simulation

Operation oriented: fleet selection

Limitations:

Simulation is separated from earth work allocation

1) User specify the route manually
(Hajjar and AbouRizk 1997, Marzouk, and Moselhi 2004)

2) Simulate with non-optimal heuristic approach
(Morley, Lu, and AbouRizk 2014)

Minimum Cost Flow (MCF) Based Method

Research objective

1) Easy to use tool

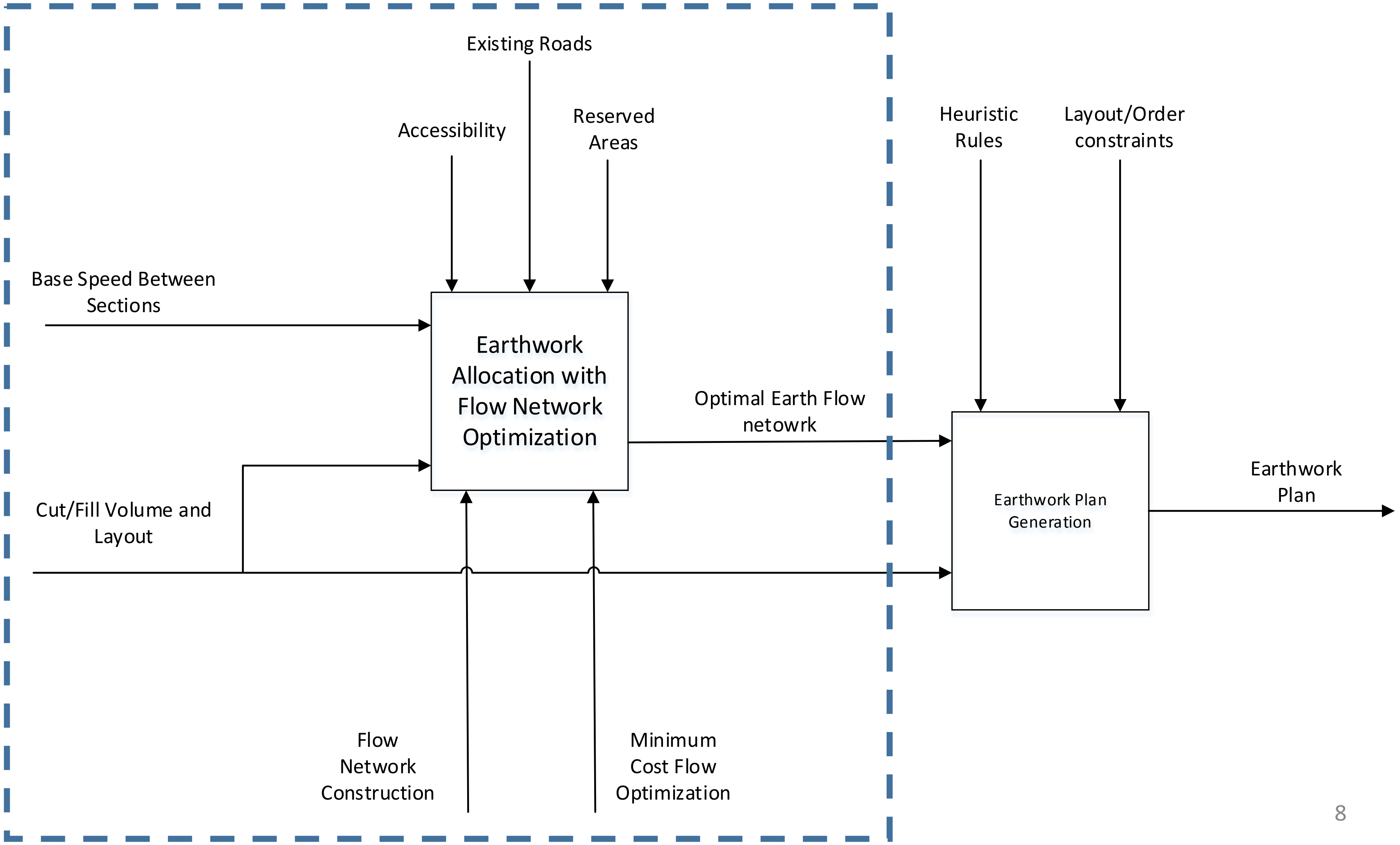
2) Accommodate “hard blocks”

3) Avoid “soft blocks”

4) Integrate time (job sequence) into earthwork planning

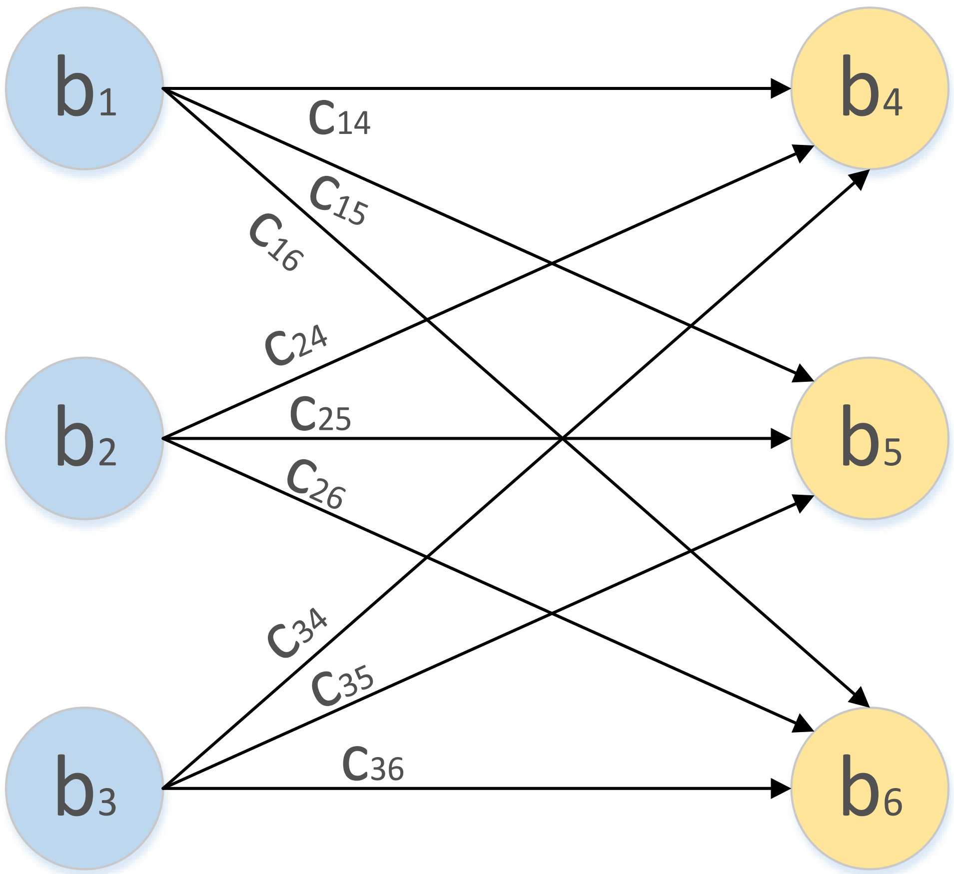
Minimum Cost Flow (MCF) Based Method

Framework



Minimum Cost Flow(MCF) Based Method

Minimum cost flow network



$$minimize \sum_{(i,j)\in A} c_{ij}x_{ij}$$

$$\sum_{j:(i,j)\in A} x_{ij} - \sum_{j:(j,i)\in A} x_{ji} = b(i) \qquad \text{for all } i \in N$$

$$l_{ij} \le x_{ij} \le u_{ij} \qquad \text{for all } (i,j) \in A$$

N is a set of n nodes
A is a set of m directed arcs

Minimum Cost Flow (MCF) Based Method

Flow network construction

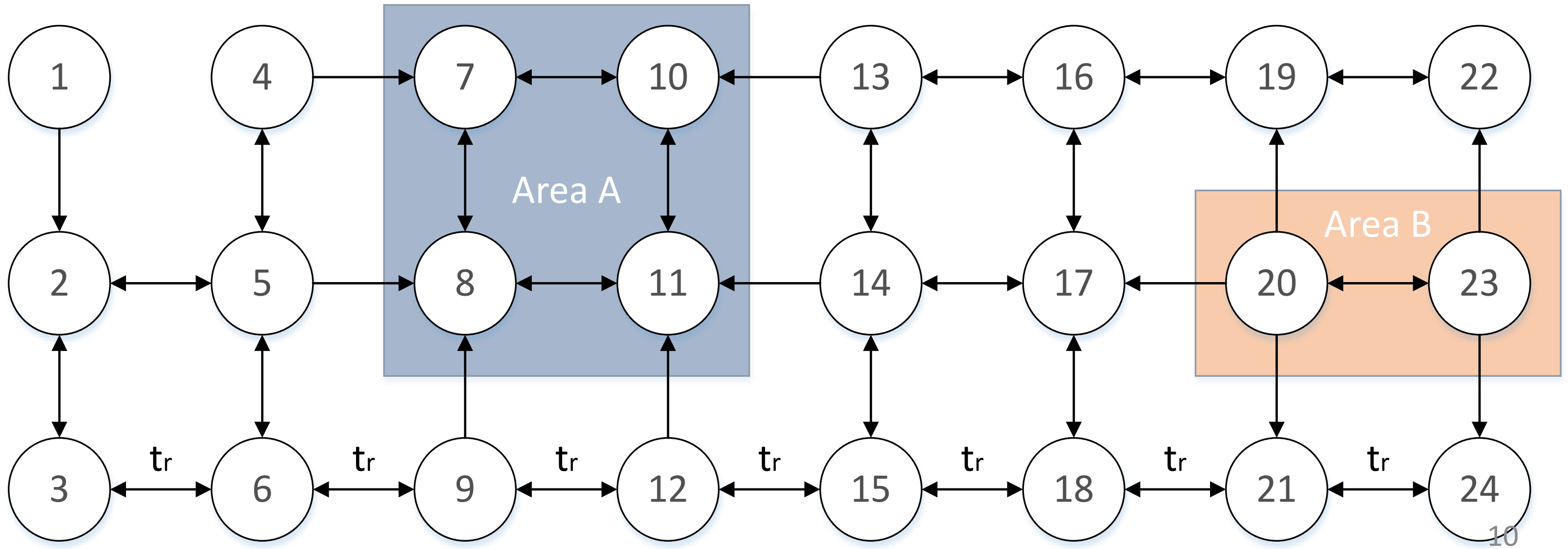
Arcs

Directions

Unit costs

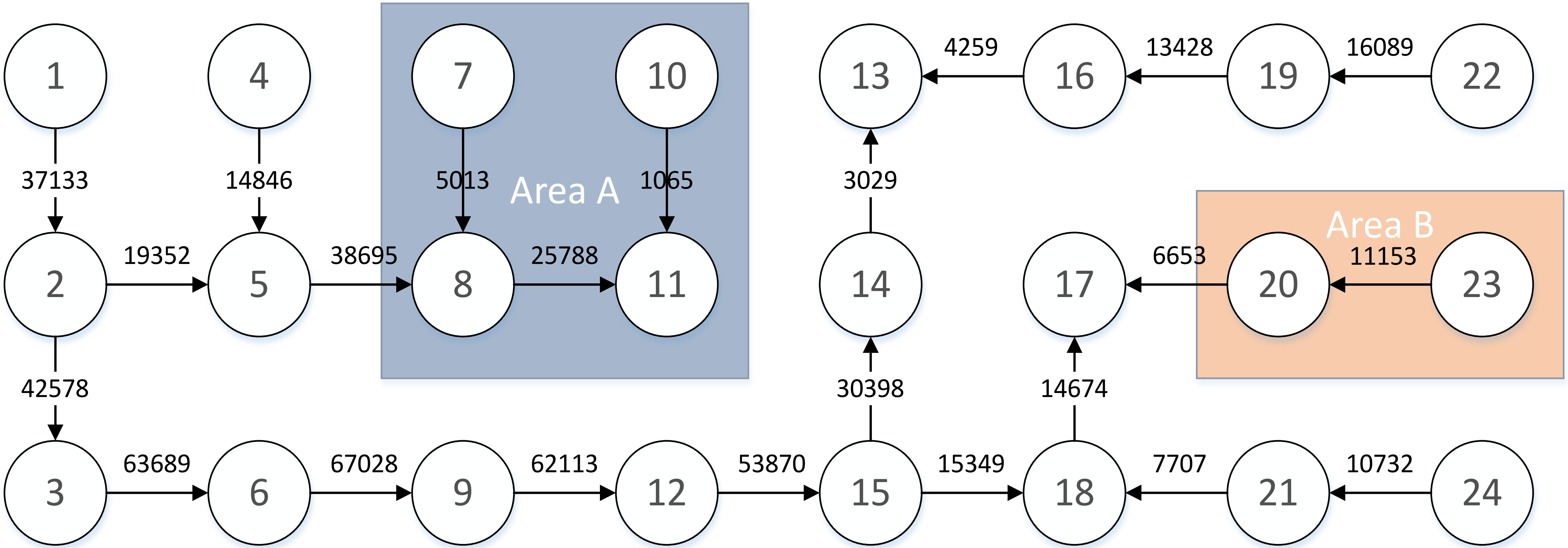
37133	14846	5013	1065	-7288	-9169	-2661	16089
24797	4497	-17920	-26853	-27369	-21327	-4500	11153
21111	3339	-4915	-8243	-8123	-8382	-3025	10732

Area A is a negative net volume area (fill);
Area B is a positive net volume area (cut).



Minimum Cost Flow (MCF) Based Method

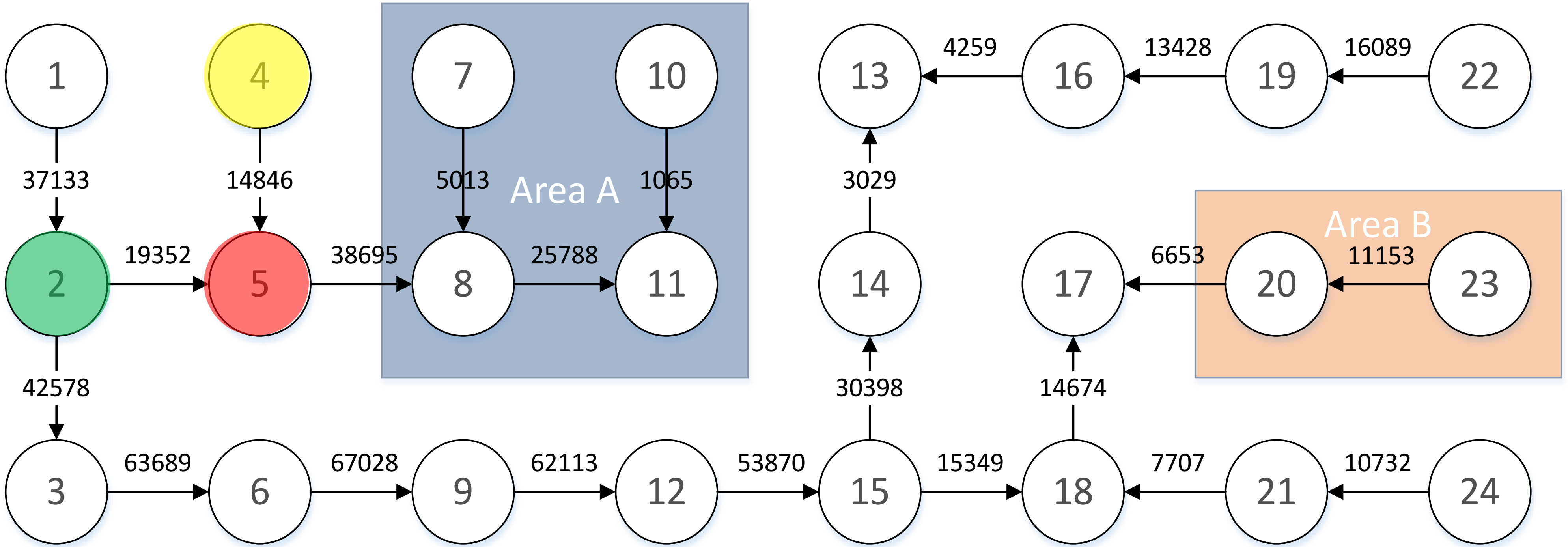
Earth Flow Network



Turning optimum material network flows into ready-to-execute haul jobs

Heuristic rules

1) Maximum flow first
2) Minimize mobilization of excavators



Haul jobs derived from optimum material flows

Sub Flow	Job	Cut	Fill	Volume	Route (R)	Predecessor
1	1	10	11	1065	-	-
2	2	22	19	2661	-	-
	3	22	16	9169	[19]	2
	4	22	13	4259	[19,16]	3
3	5	23	20	4500	-	-
	6	23	17	6653	[20]	5
4	7	5	8	4497	-	-
	8	2	8	13423	[5]	7
	9	2	11	5929	[5,8]	8

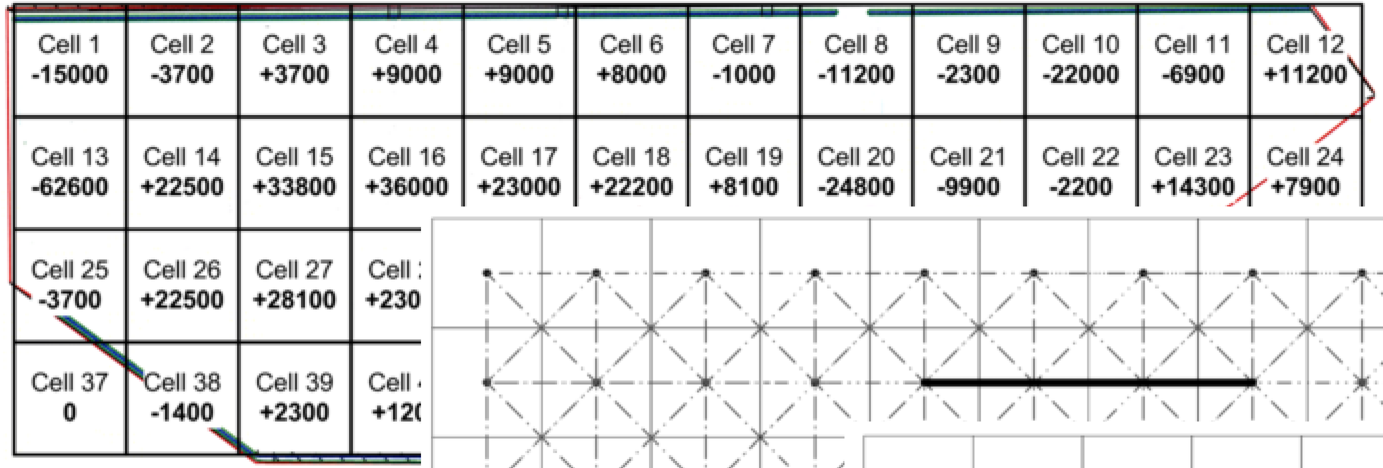
Validation & Evaluation

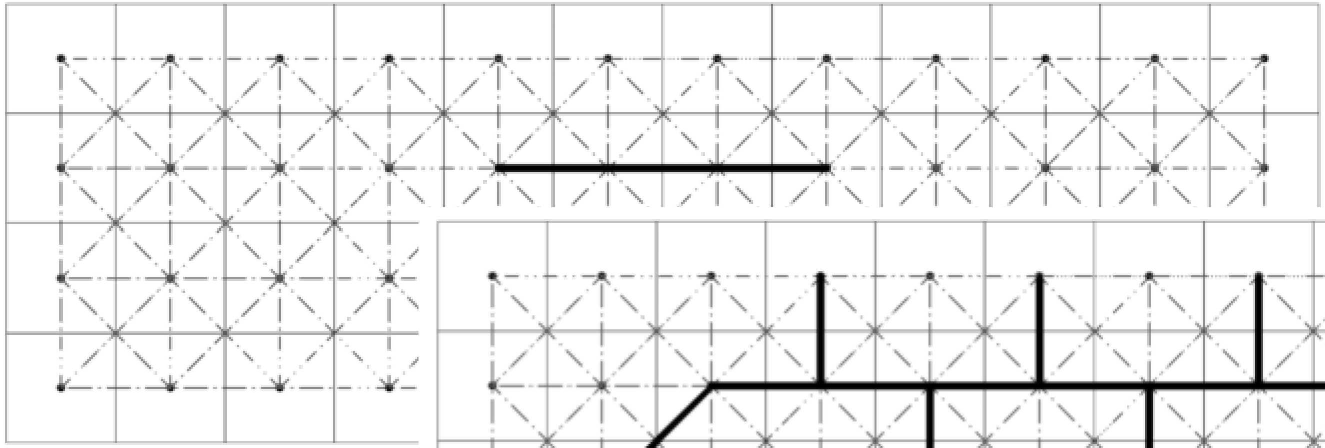
Optimal validation & evaluation

	Average weighted haul distance (m)	Haul effort (bm4)
Morley, Lu, and AbouRizk (2014) Heuristic rules	411	165,805,946
Morley, Lu, and AbouRizk (2014) Random rules	431	173,790,000
Proposed Method	401	161,543,988
Improvement compared to Random Rules	7%	8%
Improvement compared to Heuristic Rules	3%	3%

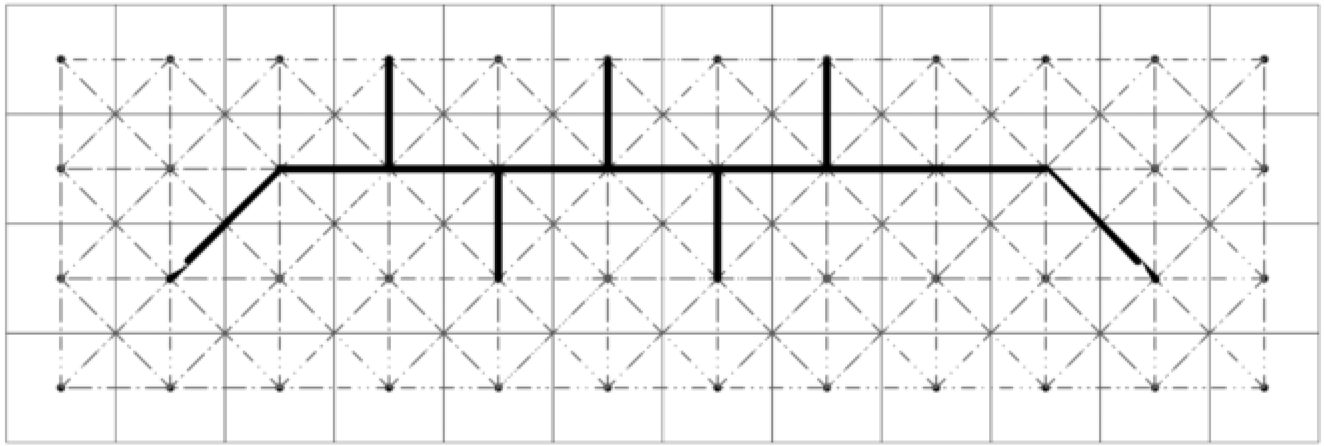
Validation & Evaluation

Block removal validation & evaluation





Layout 1



Layout 3

Validation & Evaluation

Block removal validation & evaluation

Mutual reliance of shortest path based method reaches up to 60%.

Mutual reliance is eliminated in proposed research.

Layout	Percentage of Jobs with Mutual Reliance	
	Liu and Lu (2014) (Original) with Floyd's Algorithm	Proposed Method
Layout1	34/57 = 60%	0%
Layout3	30/56 = 54%	0%

Conclusion

The paper proposed an approach which:

1) Provides an intuitive graph based interface.

2) takes job sequence and constructability into consideration.

3) Is able to generate multiple optimal solutions –practically feasible.

4) Eliminates “soft blocks”

Questions ?