Application of Operation Research Techniques in Mine Planning and Optimisation

Dr. Erkan TOPAL

Senior Lecturer, Mining Engineering Department and Senior Researcher, CRC Mining

The University of Queensland

Brisbane, Australia

Short Bibliography

Qualifications:

BSc. in Mining Engineering, SDU, Turkey, 1993
MSc. in Mining Engineering, Colorado School of Mines, 1998
MSc. in Mineral Economics, Colorado School of Mines, 2002
Ph.D. in Mining Engineering, Colorado School of Mines, 2003

Employment :

- 1993-1994., Second Shift Supervisor and Assistant Manager, Modul Marble Company, Isparta Turkey.
- 1994- 1996., Research Assistant and Teaching Assistant, at Suleyman Demirel University, Mining Engineering Department, Isparta, Turkey.
- 1997-2003., Teaching Assistant, at Colorado School of Mines, Mining Engineering Department, Colorado, U.S.A.
- Summer 2001., Research Associate in Kiruna Mine,Kiruna, Sweden .
- Aug. 2005-Dec.2005., Research Associate, Mining Engineering Department, McGill University, Canada Research Chair & BHP Billiton Chair in Mine Planning Optimization, Montreal, Canada.
- Fall 2003-April 14 2006, Assistant Professor, at Dicle University, Mining Engineering Department, Diyarbakir, Turkey.
- Jan 2007-Feb23 2007., Strategic Mine Planning Department, Pilbara Iron Ore District, Rio Tinto, Perth, Australia.
- April 25-Present., Senior Lecturer and Senior Researcher, Mining Engineering Department, CRC Mining, The University of Queensland Brisbane, Australia.

Outline

- **Underground Mine Scheduling Using Mixed Integer Programming: Application at Kiruna Mine, Sweden**
- **Schedule of Brockman District, Rio Tinto, Australia by Network Flow Model**

Underground Mine Scheduling Using Mixed Integer Programming:
Application at Kiruna Mine, Sweden

Linear Programming

Minimize (or maximize)

$$Z=c_1x_1+c_2x_2+\ldots\ldots\ldots\ldots+c_nx_n$$

Subject To:

$$a_{11}x_1+a_{12}x_2+\ldots\ldots\ldots\ldots\ldots+a_{1n}x_n=b_1$$

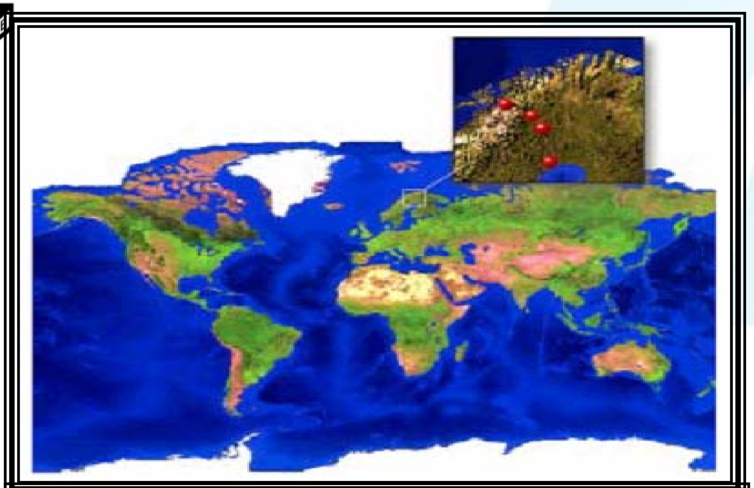
$$a_{21}x_1+a_{22}x_2+\ldots\ldots\ldots\ldots\ldots+a_{2n}x_n = b_2$$

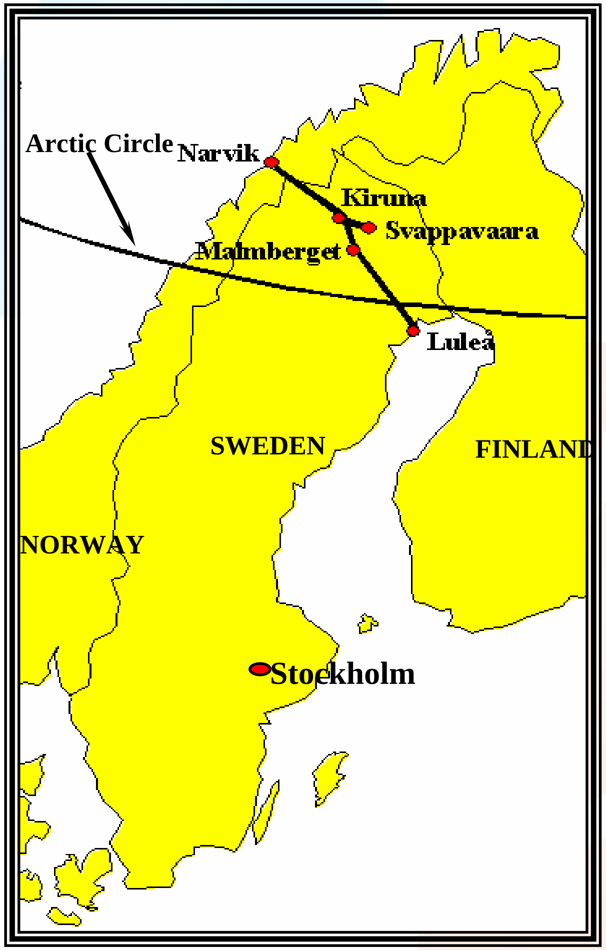
$$x_{1,}\ x_2\ldots\ldots\ldots\ldots\ldots \quad x_n >= 0$$

Integer Programming and MIP

$x_1,x_2,x_3\ldots\ldots\ldots x_n$ nonnegative integer values

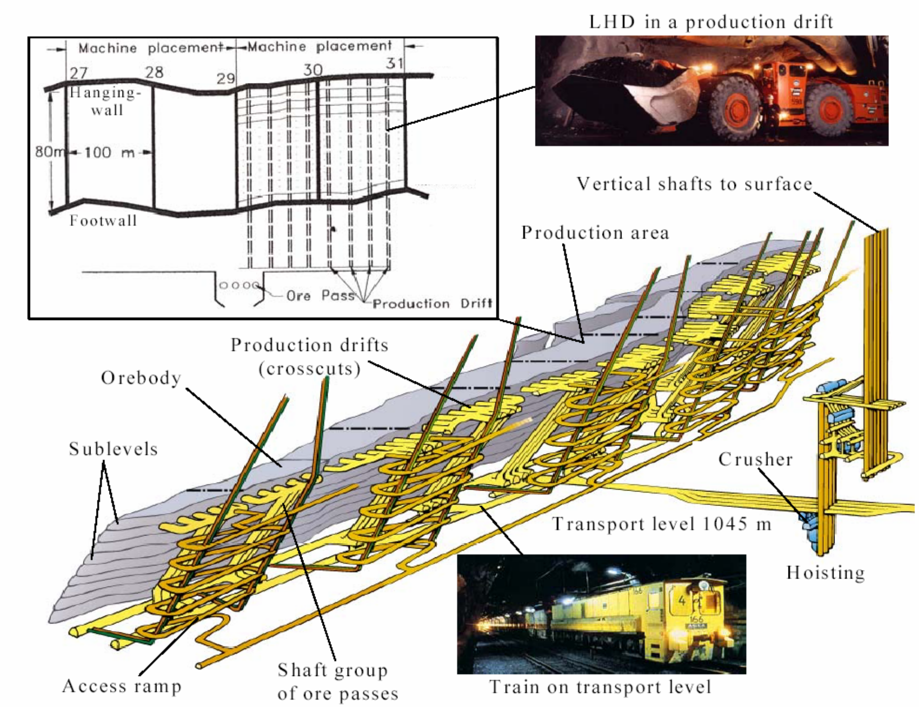
The Kiruna Mine ?





- Kiruna produced 24 Mt. of iron ore.
- Kiruna has 1,800 employees.

What is the Purpose of the work?



To efficiently run the mill the mine must deliver certain quantity of three ore types.

Mixed Integer Programming (MIP) used to schedule Kiruna's Operation, specifically, which production block to mine and when to mine in order to meet the monthly planned production

Mathematical Model

Objective Function:

Minimize total deviation above and below planned production quantities across all ore types and time periods

Constraints:

- Account for deviations as a function of what is being mined in each time period of each ore type (B1, B2 and D3):

- Vertical sequencing constraints between sublevels:

- Adjacent sequencing constraints between machine placements:

- Limits on the number of active machine placements within a shaft group:

First Year Schedule

lachine Placement	Level		201	202	203	204	205	206	207	208	209	210	211	212	Total
765 42- 43	45	1													690
765 44- 46	45	2													1680
792 14- 15	16	1													1630
792 19- 21	19	2													130
792 33- 34	33	2													540
792 35- 37	37	1													420
792 39- 42	40	1													1760
792 43- 46	45	2													750
818 16- 17	16	2													650
820 16- 17	16	2													150
820 18- 19	19	1													1160
820 23- 26	25	1													1120
820 27- 28	28	1													1250
820 29- 30	28	2													260
820 31- 32	33	1													1650
820 33- 34	33	2													1600
820 35- 37	37	1													1690
820 38- 41	40	1													770
849 27- 28	28	1													930
849 29- 30	28	2													1210
849 31- 34	33	1													820
849 35- 38	37	1													140
Development Ore															1560
Development Waste															996
Total Kton/Month			2053	1983	1973	1913	1883	1913	2063	2143	1983	1853	1823	1973	23556
Total Kton/Day			66.2	70.8	63.6	63.8	60.7	63.8	66.5	69.1	66.1	59.8	60.8	63.6	
B1 Kton/Day			11.9	11.4	11.0	11.3	10.3	11.0	11.6	11.9	11.8	11.3	11.0	10.0	
B2 Kton/Day			29.8	31.5	27.2	28.8	27.2	30.1	30.7	31.7	29.6	24.6	24.4	27.2	
D3 Kton/Day			24.5	27.9	25.5	23.7	23.2	22.7	24.2	25.5	24.7	23.9	25.3	26.5	
Month			201	202	203	204	205	206	207	208	209	210	211	212	

Proposed Schedule vs. Current Kiruna Mine Schedule

Method	Solution Time	% Deviation from The Target	# of Constraint Violation
Kiruna Mine Manual Schedule	3 days	10 – 15 %	Several
Propose MIP Schedule	<100 seconds	6.32 %	No violation

Conclusions

- The mine is currently using the developed model as a scheduling tool for their operation
- This research presents a way to successfully solve multi-period production scheduling for a large scale underground mine

Schedule of Brockman District, Rio Tinto, Australia by Network Flow Model

What is the Purpose of the work?

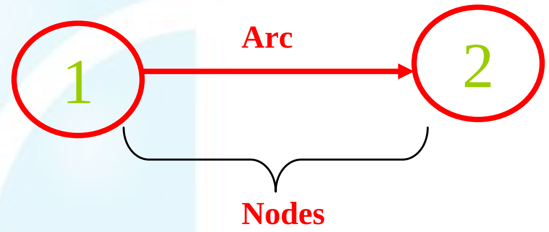
Generate a strategic scheduling for Pilbara Iron operation that will maximise the Net Present Value (NPV) of the operation.

It will also provide answers for the following strategic planning questions:

1. When should a plant start operation
2. When should Green field deposits start mining
3. What should be the optimum capacities for mines, plants, and trains
4. Other possible questions from business

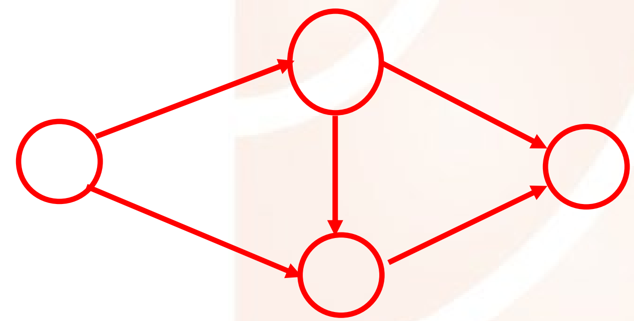
Background

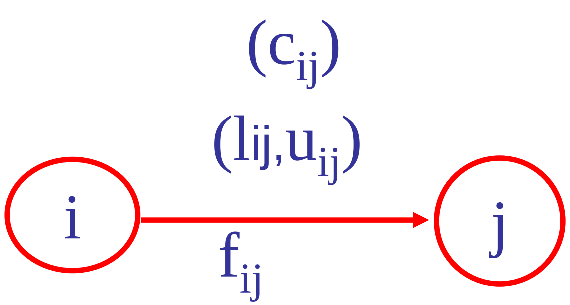
Arc: a line connecting two nodes



Nodes: also called vertices, points and junctions indicates beginning and ending of an arc

Network: Set of arcs and nodes





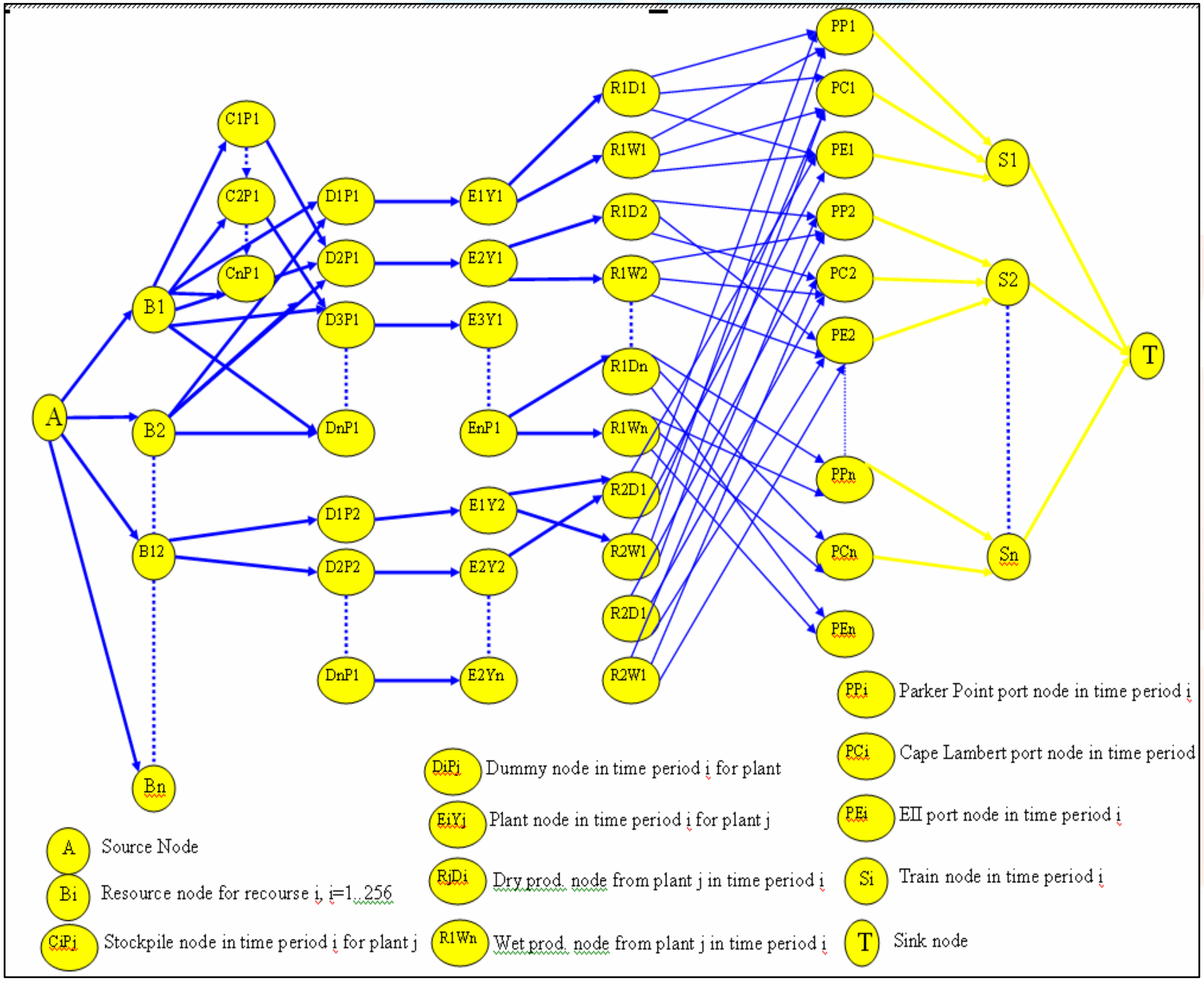
u_{ij} is the max capacity of flow on arc a_{ij}

lij is the minimum capacity of flow on arc aij

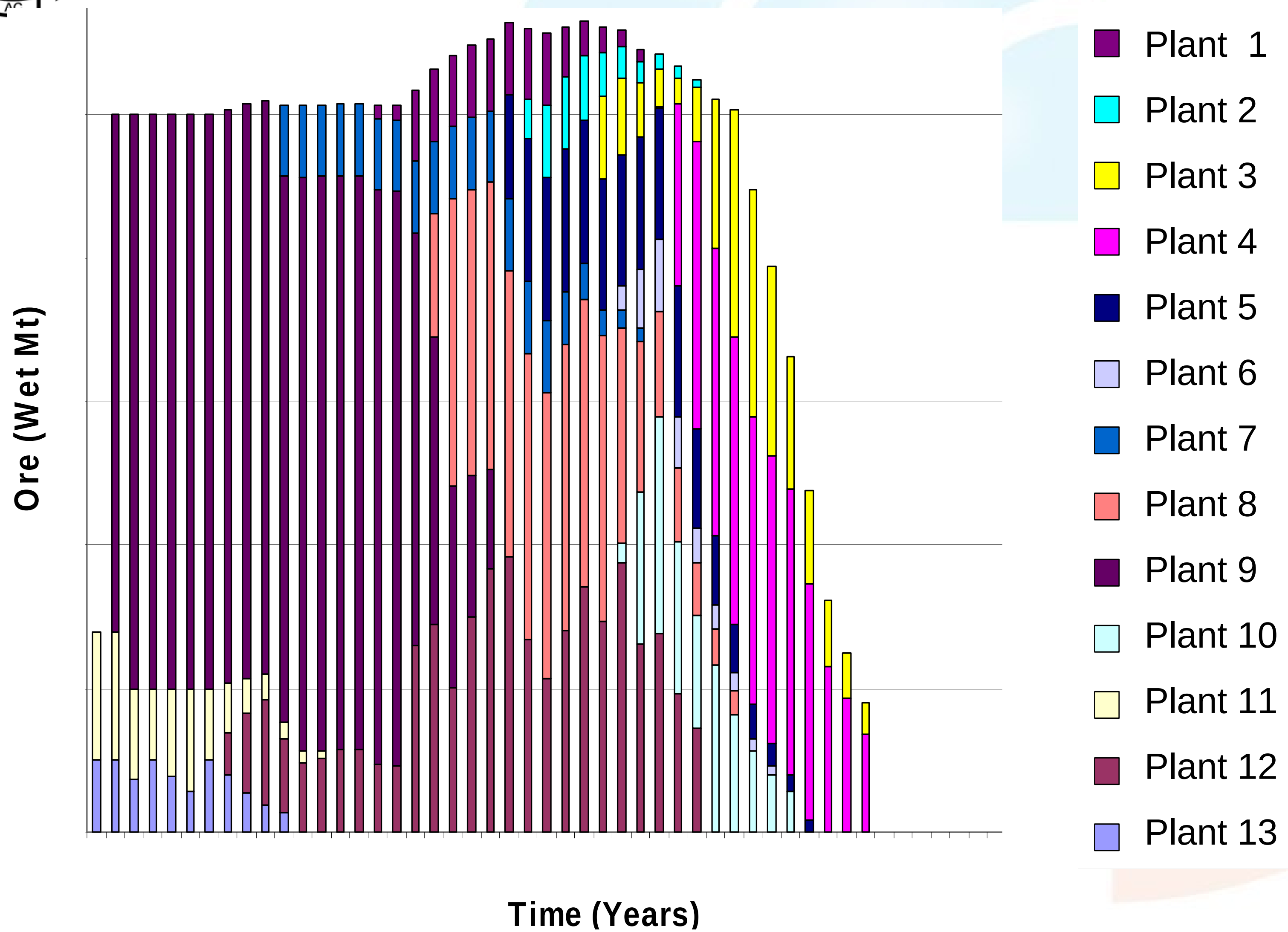
f_{ij} the amount of flow sent from i to j

C_{ij} the unit cost of flow sent from i to j

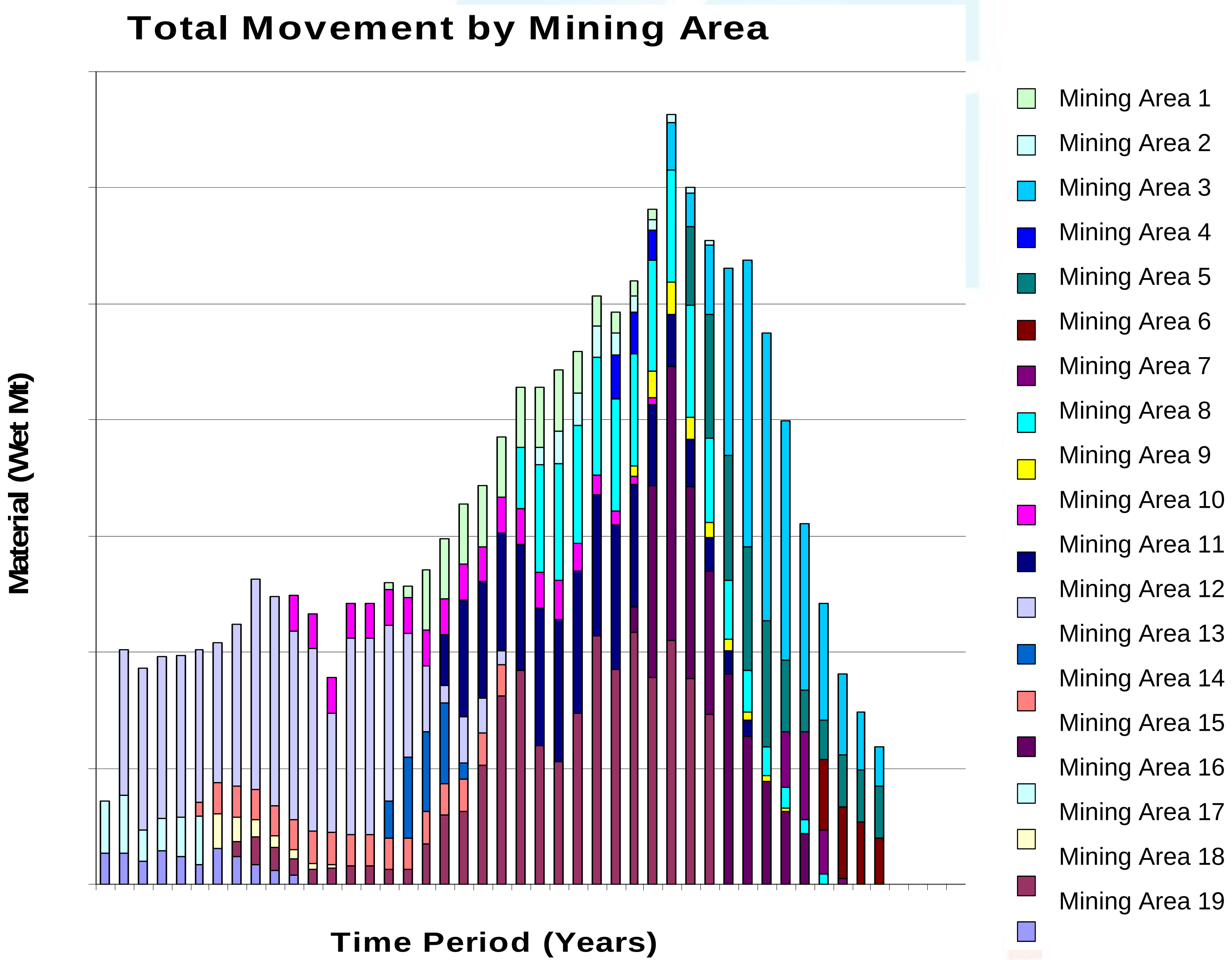
Maximum Flow Networks for Pilbara Districts



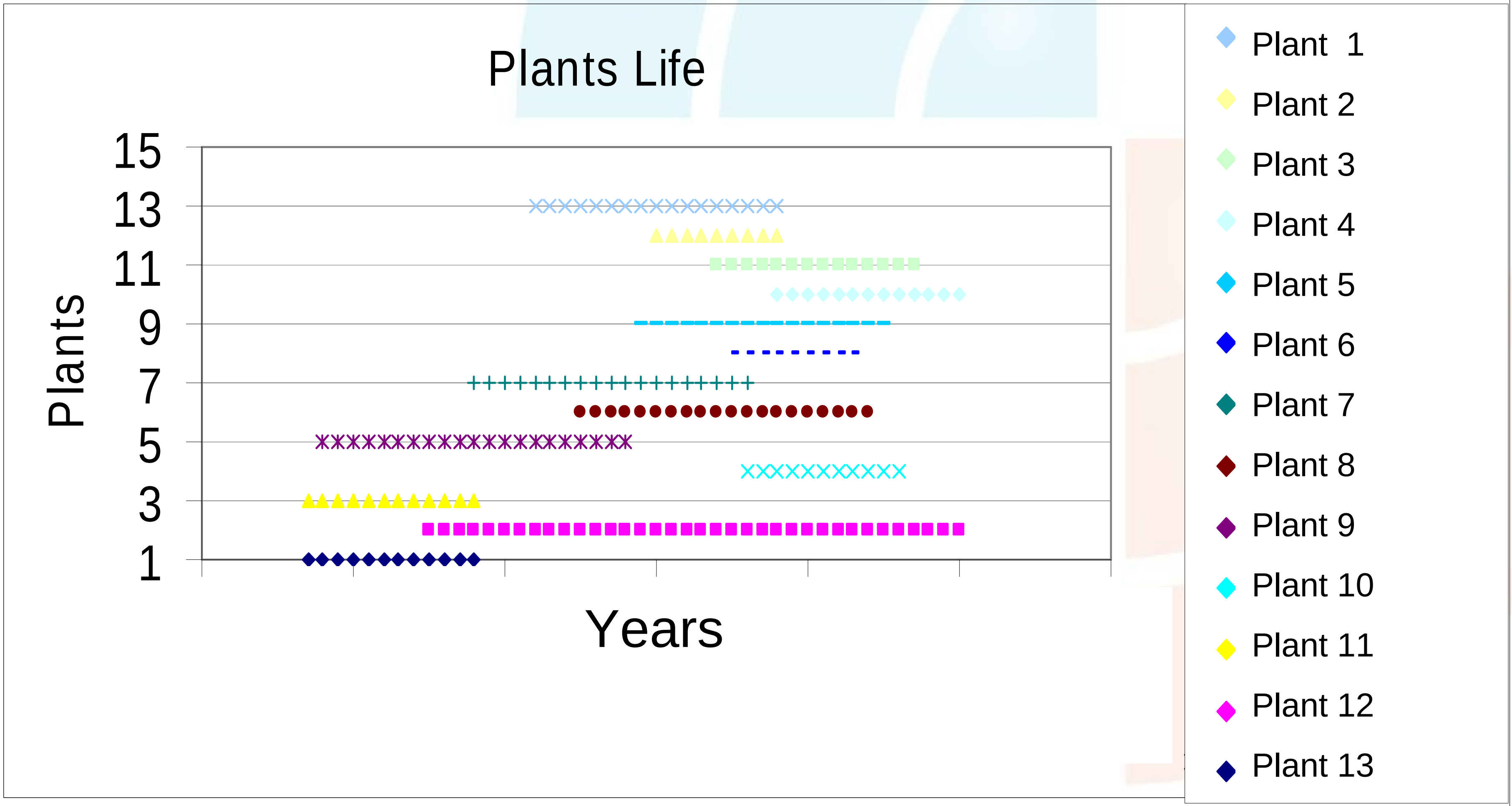
Ore Production



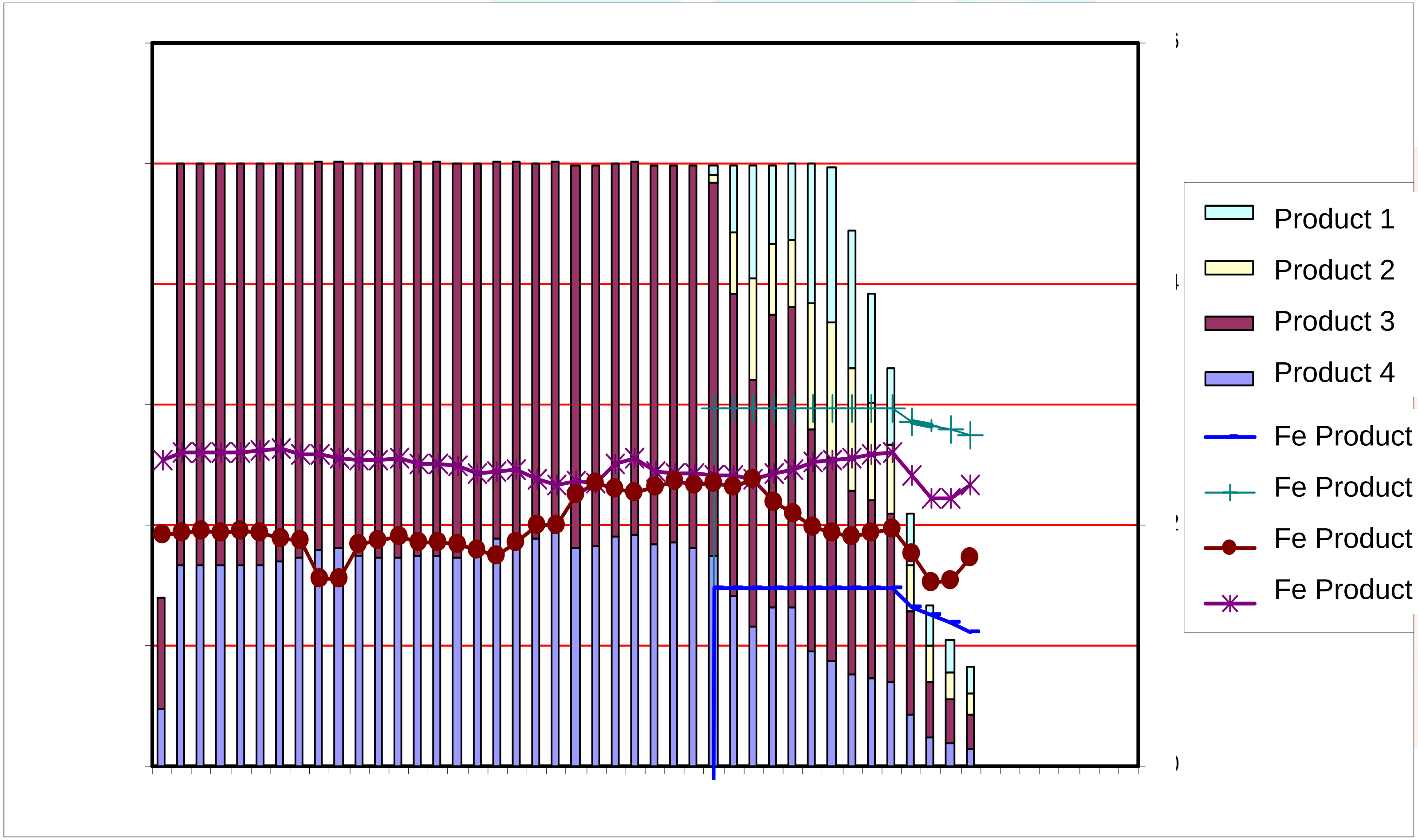
Total Ore Movement by Mining area



Plants Life (starting and ending times)



PB and PIS lump and fines tonnes and Fe grade



Conclusions

- Strategic scheduling problem is represented as a network flow model
- The optimum result for the problem is determined within seconds; <5 seconds
- The model has flexibility to handle stockpiling options
- Within seconds, it can optimise very large models that can not be handled by any other existing scheduling tools without loosing optimality

ANY QUESTIONS ?