

## **Identifying Optimal Mining Sequences for Continuous Miners**

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# Presentation Outline

- ❖ **Background and Current Practice**
- ❖ **Need for Optimization Tool**
- ❖ **Dynamic Programming**
- ❖ **Dynamic Programming Algorithm**
- ❖ **Application Case Study**
- ❖ **Acknowledgements**

# Background and Current Practice

MATHEMATICAL MODEL OF PRODUCTION -- LOADING AND HAULING ROUTINE  
35 FT CUTS, 5 FT HT, 9 T SH CAR AND 10 / 6 TPM LDG RATE, 40% REJ

INPUT DATA \*\*\*\* FOR THE OVERALL SYSTEM

NUMBER OF CUTS	=	52 CUTS	
SHIFT LENGTH	=	480 MIN	SHUTTLE CAR PAYLOAD 9 TN
MAX PLCS BOLTO/SHIFT	=	12 CUTS	LOADING RATE (STNDRD) 10 TN/MIN
RAVEL IN + OUT	=	60 MIN	LOADING RATE (CLN UP) 6 TN/MIN
*REP TO STRT + LV	=	0 MIN	SH CAR SPEED -CP TO LDR 275 FPM
*UNCH	=	0 MIN	SH CAR SPEED -LDR TO CDR 300 FPM
SERVICE MINER	=	20 MIN	SH CAR SPEED -CP TO DMP 300 FPM
JNEXPCTD DELAY	=	0 MIN	SH CAR SPEED -LDR TO GP 300 FPM
MINING THICKNESS	=	60 IN	TRAM TIME PER MIN 0.75 MIN
WIDTH OF CUT	=	28 FT	LENGTH OF TRAM 28 FT
RAW COAL DENSITY	=	105 LB/CU FT	LENGTH OF SHUTTLE CAR 28 FT
REJECT	=	0 PCT	TRAM SPEED OF MINER 30 FPM
*ONS PER FOOT	=	5.4	FEET PER CAR 1.67

## Input Section

### Equipment Characteristics

#### Operating rates

#### Capacities

### Human Resource Data

#### Shift schedule

#### Staffing levels

### Geologic Data

#### Seam height

#### Material densities

### Geometric Data

#### Haulage routes

#### Cut sequence

## SSP Model

35 FT CUTS, 5 FT HT, 9 T SH CAR AND 10 / 6 TPM LDG RATE, 40% REJ

*****INTERMEDIATE OUTPUT*****											
CUT NUM	TONS IN CUT	LOADS PER CUT	LOADING RATE	CH OUT DIST	CH OUT TIME	HAUL DIST	WT NO SH CAR PR OCCUR	CUT NUM	TONS IN CUT	LOADS PER CUT	LOADING RATE
1	189.00	21.0	9.4	140	0.97	172	0.02	1	189.00	21.0	9.4
2	189.00	21.0	9.4	70	0.48	172	0.51	2	189.00	21.0	9.4
3	189.00	21.0	9.4	70	0.48	102	0.05	3	189.00	21.0	9.4
4	189.00	21.0	9.4	70	0.48	172	0.51	4	189.00	21.0	9.4
5	189.00	21.0	9.4	70	0.48	102	0.05	5	189.00	21.0	9.4
6	189.00	21.0	9.4	70	0.48	172	0.51	6	189.00	21.0	9.4
7	189.00	21.0	9.4	70	0.48	172	0.02	7	189.00	21.0	9.4
8	189.00	21.0	9.4	70	0.48	172	-0.03	8	189.00	21.0	9.4
9	162.00	18.0	9.3	77	0.54	172	0.46	9	162.00	18.0	9.3
10	162.00	18.0	9.3	77	0.54	102	-0.01	10	162.00	18.0	9.3
11	162.00	18.0	9.3	77	0.54	172	0.46	11	162.00	18.0	9.3
12	162.00	18.0	9.3	77	0.54	102	-0.01	12	162.00	18.0	9.3
13	162.00	18.0	9.3	77	0.54	172	0.46	13	162.00	18.0	9.3
14	162.00	18.0	9.3	77	1.20	172	-0.20	14	162.00	18.0	9.3
15	162.00	18.0	9.3	77	1.22	172	-0.22	15	162.00	18.0	9.3
16	162.00	18.0	9.3	77	0.71	172	0.29	16	162.00	18.0	9.3
17	162.00	18.0	9.3	77	0.71	172	0.27	17	162.00	18.0	9.3
18	162.00	18.0	9.3	77	0.71	172	-0.18	18	162.00	18.0	9.3
19	162.00	18.0	9.3	77	0.71	172	-0.20	19	162.00	18.0	9.3
20	162.00	18.0	9.3	77	0.71	172	0.29	20	162.00	18.0	9.3
21	162.00	18.0	9.3	77	0.71	172	0.27	21	162.00	18.0	9.3
22	162.00	18.0	9.3	77	0.71	172	-0.18	22	162.00	18.0	9.3
23	162.00	18.0	9.3	77	0.71	172	-0.20	23	162.00	18.0	9.3
24	162.00	18.0	9.3	77	0.71	172	0.29	24	162.00	18.0	9.3
25	162.00	18.0	9.3	77	1.22	172	-0.22	25	162.00	18.0	9.3
26	162.00	18.0	9.3	77	0.97	242	0.49	26	162.00	18.0	9.3
27	162.00	18.0	9.3	77	0.97	242	0.58	27	162.00	18.0	9.3
28	162.00	18.0	9.3	77	0.97	242	0.51	28	162.00	18.0	9.3
29	162.00	18.0	9.3	77	0.97	242	0.58	29	162.00	18.0	9.3
30	162.00	18.0	9.3	77	0.97	242	0.51	30	162.00	18.0	9.3
31	162.00	18.0	9.3	77	0.97	242	0.58	31	162.00	18.0	9.3
32	162.00	18.0	9.3	77	0.97	242	0.51	32	162.00	18.0	9.3
33	162.00	18.0	9.3	77	0.97	242	0.58	33	162.00	18.0	9.3
34	162.00	18.0	9.3	77	0.97	242	0.51	34	162.00	18.0	9.3
35	162.00	18.0	9.3	77	0.97	242	0.58	35	162.00	18.0	9.3
36	162.00	18.0	9.3	77	0.97	242	0.51	36	162.00	18.0	9.3
37	162.00	18.0	9.3	77	0.97	242	0.58	37	162.00	18.0	9.3
38	162.00	18.0	9.3	77	0.97	242	0.51	38	162.00	18.0	9.3
39	162.00	18.0	9.3	77	0.97	242	0.58	39	162.00	18.0	9.3
40	162.00	18.0	9.3	77	0.97	242	0.51	40	162.00	18.0	9.3
41	162.00	18.0	9.3	77	1.22	242	0.25	41	162.00	18.0	9.3
42	162.00	18.0	9.3	77	1.22	242	0.75	42	162.00	18.0	9.3
43	162.00	18.0	9.3	77	1.22	242	0.74	43	162.00	18.0	9.3
44	162.00	18.0	9.3	77	1.22	242	0.29	44	162.00	18.0	9.3
45	162.00	18.0	9.3	77	1.22	242	0.75	45	162.00	18.0	9.3
46	162.00	18.0	9.3	77	1.22	242	0.74	46	162.00	18.0	9.3
47	162.00	18.0	9.3	77	1.22	242	0.75	47	162.00	18.0	9.3
48	162.00	18.0	9.3	77	1.22	242	0.29	48	162.00	18.0	9.3
49	162.00	18.0	9.3	77	1.22	242	0.75	49	162.00	18.0	9.3
50	162.00	18.0	9.3	77	1.22	242	0.74	50	162.00	18.0	9.3
51	162.00	18.0	9.3	77	1.22	242	0.25	51	162.00	18.0	9.3
52	162.00	18.0	9.3	77	1.22	242	0.25	52	162.00	18.0	9.3
8532.00		948.0	483.0	5424	37.80	9644.0	18.69				

SUMMARY OF RESULTS

TIME AVAILABLE TO MINE	400 MIN
UNEFFECTED DELAYS	60 MIN
EXPECTED MINING TIME	340 MIN
EXPECTED PRODUCTION	1008 TONS/SHIFT (RAW)
EXPECTED MINING RATE	2.97 TONS/MIN

	AVGE	AVGE
	PER CUT	PER SHF
LOAD TIME	916	17.6
CH OUT TIME	686	13.2
WT NO SH CAR	171	3.3
IN-CUT DELAYS	400	7.7
TRAM TIME	705	13.6
CYCLE TIME	2877.5	
FEET		

## Output Section

### Cycle Times

#### Loading

#### Change-out

#### Wait on car

#### Tram

### Delays

### Production

#### Tons

#### Feet of advance

### Mining Rates

LOAD TIME	CH OUT TIME	WT NO SH CAR PR OCCUR	IN CUT DELAYS	TRAM TIME	CYCLE TIME	CUM PROD RATE	CUM TONS	CUM TIME
20.1	10.2	0.5	4.0	13.2	52.6	3.26	189	57.9
20.1	10.2	0.5	4.0	13.2	52.6	3.42	378	110.5
20.1	10.2	0.5	4.0	13.2	52.6	3.58	567	158.4
20.1	10.2	0.5	4.0	13.2	52.6	3.58	756	210.9
20.1	10.2	0.5	4.0	13.2	52.6	3.65	945	258.8
20.1	10.2	0.5	4.0	13.2	52.6	3.64	1134	311.4
20.1	20.4	0.2	4.0	30.2	74.9	3.42	1323	386.3
17.4	18.4	0.0	20.0	11.7	67.5	3.27	1485	453.8
17.4	9.7	3.7	20.0	11.7	62.4	3.19	1647	516.2
17.4	9.7	3.7	20.0	11.7	62.4	3.19	1809	575.0
17.4	9.7	3.7	20.0	11.7	62.4	3.19	1971	637.4
17.4	9.7	3.7	20.0	11.7	62.4	3.19	2133	696.1
17.4	9.7	3.7	20.0	11.7	62.4	3.19	2295	775.8
12.0	14.4	0.0	4.0	5.2	36.6	2.96	2403	811.4
20.1	25.5	0.0	4.0	13.7	65.8	2.95	2592	874.7
12.0	8.5	1.4	4.0	5.2	31.1	2.98	2700	905.8
20.1	15.3	2.7	4.0	13.7	55.7	3.00	2889	961.6
12.0	8.5	0.0	4.0	5.2	29.7	3.02	2997	991.3
20.1	15.3	2.7	4.0	13.7	55.7	3.05	3186	1044.3
12.0	8.5	1.4	4.0	5.2	31.1	3.06	3294	1075.5
20.1	15.3	2.7	4.0	13.7	55.7	3.08	3483	1131.2
12.0	8.5	0.0	4.0	5.2	29.7	3.09	3591	1160.9
20.1	15.3	2.7	4.0	13.7	55.7	3.11	3780	1214.0
12.0	8.5	1.4	4.0	5.2	31.1	3.12	3888	1245.1
20.1	15.3	2.7	4.0	13.5	55.6	3.13	4077	1300.7
20.1	25.5	0.0	4.0	43.3	93.0	3.06	4266	1393.6
20.1	20.4	4.9	4.0	13.2	62.6	3.06	4455	1456.2
20.1	10.2	9.8	4.0	13.2	57.2	3.07	4644	1513.5
20.1	10.2	5.1	4.0	13.2	52.6	3.09	4833	1566.0
20.1	10.2	9.8	4.0	13.2	57.2	3.09	5022	1623.3
20.1	10.2	5.1	4.0	13.2	52.6	3.11	5211	1675.8
20.1	10.2	9.8	4.0	13.2	57.2	3.12	5400	1733.0
20.1	20.4	4.9	4.0	30.2	79.6	3.08	5589	1812.6
17.4	18.4	3.5	10.0	11.7	71.0	3.05	5751	1883.7
17.4	9.7	7.4	20.0	11.7	66.1	3.03	5913	1949.8
17.4	9.7	3.7	20.0	11.7	62.4	3.02	6075	2012.2
17.4	9.7	7.4	20.0	11.7	66.1	3.00	6237	2078.3
17.4	9.7	3.7	20.0	11.7	62.4	2.99	6399	2140.8
17.4	9.7	7.4	20.0	11.7	66.1	3.00	6561	2224.2
12.0	14.4	1.3	5.2	5.2	36.6	2.98	6723	2261.1
20.1	25.5	2.5	4.0	13.7	65.8	2.95	6885	2326.9
12.0	8.5	3.8	4.0	5.2	33.5	2.95	6966	2360.3
20.1	15.3	2.4	4.0	13.7	60.4	2.96	7155	2420.8
12.0	8.5	1.4	4.0	5.2	31.1	2.96	7263	2451.9
20.1	15.3	2.7	4.0	13.5	55.7	2.97	7452	2507.6
12.0	8.5	3.8	4.0	5.2	33.5	2.98	7560	2541.1
20.1	15.3	7.4	4.0	13.7	60.4	2.98	7749	2601.5
12.0	8.5	1.4	4.0	5.2	31.1	2.98	7857	2632.6
20.1	15.3	2.7	4.0	13.7	55.7	2.99	8046	2688.4
12.0	8.5	3.8	4.0	5.2	33.5	3.00	8154	2721.8
20.1	15.3	7.4	4.0	13.5	60.2	3.00	8343	2782.1
20.1	25.5	2.5	4.0	43.3	95.4	2.97	8532	2877.5
915.6	686.1	170.5	400.9	705.3	2877.5			

# Background and Current Practice

The image shows a 3D architectural floor plan of a building. The plan is divided into a grid of rooms. The top section consists of six large rectangular rooms, each with a smaller rectangular area at the top. These rooms are labeled with numbers 1 through 6. The bottom section consists of a central corridor running horizontally, flanked by two rows of smaller rectangular rooms. The central corridor is labeled with letters R, T, B, and I. The rooms are arranged in a symmetrical pattern around the central corridor.



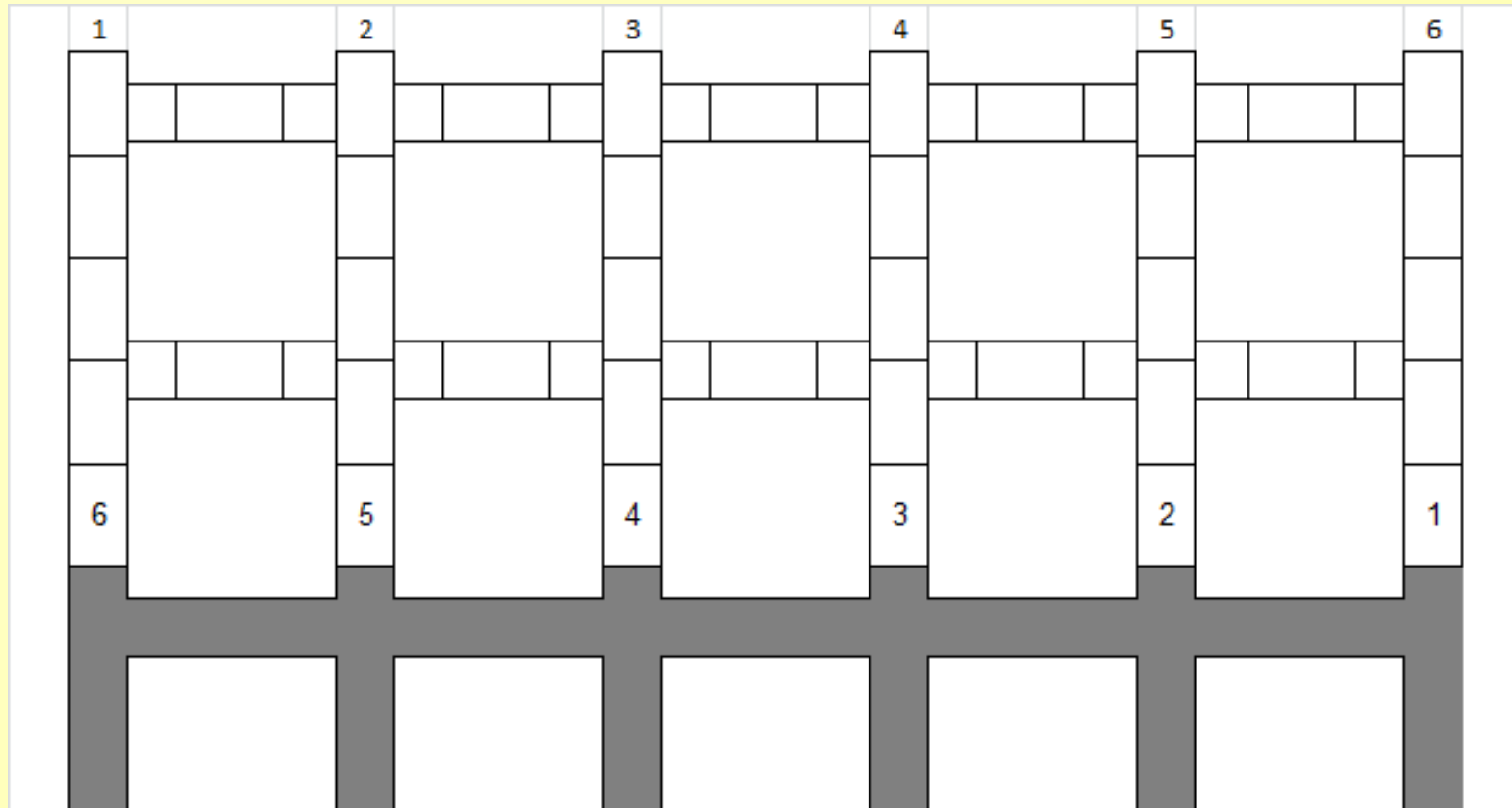
# Background and Current Practice

1				2				3				4				5				6															
45	50	55	60	44	49	54	59	43	48	53	58	42	47	52	57	41	46	51	56	40															
39				38				37				36				35				34															
18				17				16				15				14				13															
12				23				28				33				11				22	27	32	10	21	26	31	9	20	25	30	8	19	24	29	7
6				5				4				3				2				1															
R				R				T				B				I				I															

# Background and Current Practice

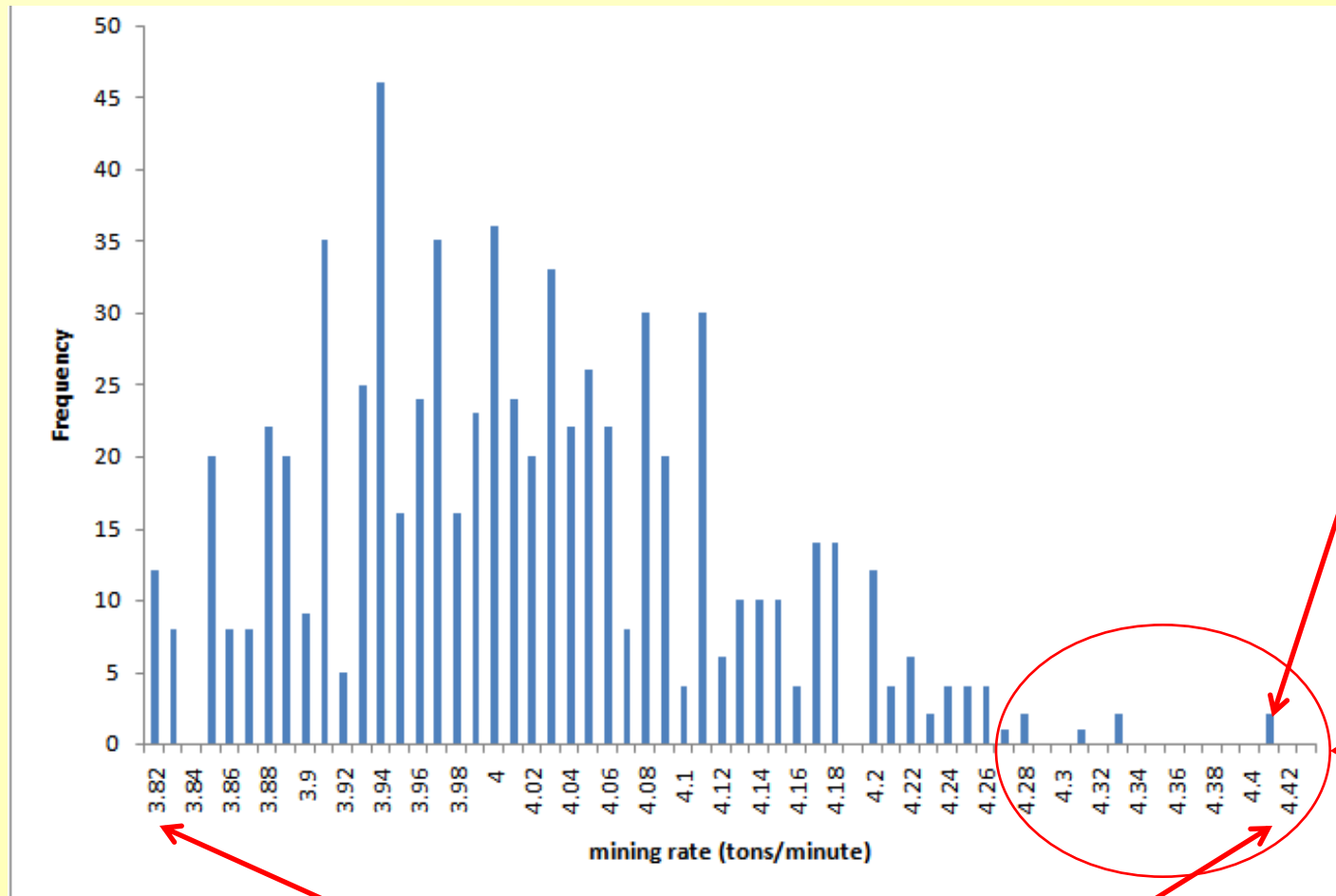
1			2			3			4			5			6	
48	51	47	38	40	37	21	29	31	34	26	42	45	43	49	52	50
41			33			13			17			36			46	
39			14			5			10			23			44	
28	32	27	8	20	16	3	7	9	12	6	22	25	18	30	35	24
15																
<div></div>																
<div></div>																
R			R			T			B			I			I	

# Need for Optimization Tool



720 different sequences

# Need for Optimization Tool



2 of 720  
are  
optimal

8 of 720  
(only 1%)  
are in the top  
25% of the  
productivity  
range

15% improvement between  
best case and worst case

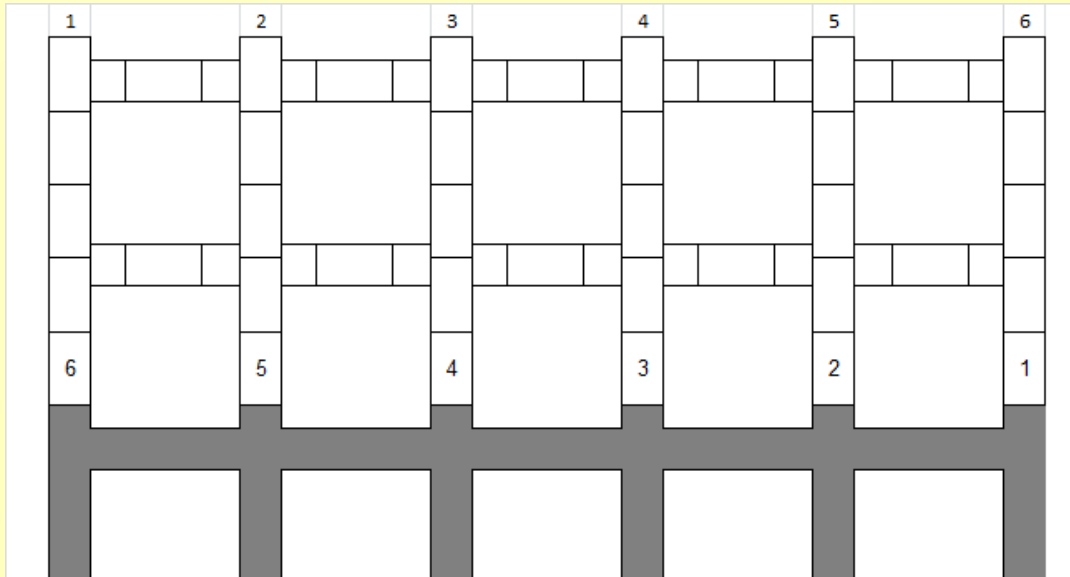


# Dynamic Programming

- ❖ **Dynamic programming is a recursive, or step-by-step, approach to solving optimization problems.**
- ❖ **At each step, referred to as a STAGE, parameters and constraints of all FEASIBLE options or STATES are evaluated using an OPTIMAL VALUE FUNCTION.**
- ❖ **This requires the following items to be defined:**
  - **Stages**
  - **Feasible states at each stage**
  - **Optimal value function (OVF)**
  - **Recurrence relation**

# Dynamic Programming

- In room-and-pillar mining:
  - Stages are cuts to be mined



- Feasible states at each stage are cuts satisfying boundary conditions and constraints

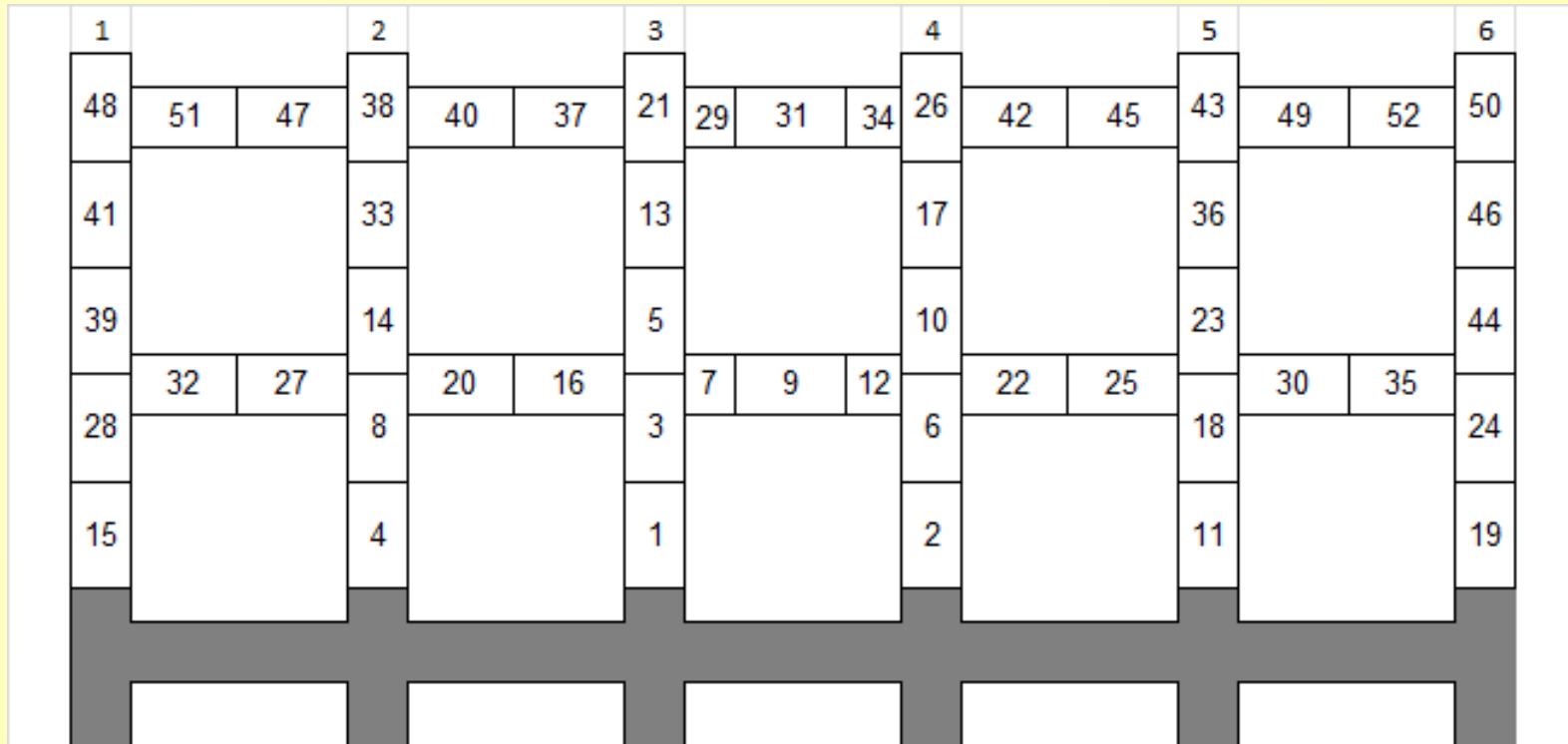
# Dynamic Programming

## Constraint Matrix

	Bolting	Ventilation
Regulatory	<ul style="list-style-type: none"><li>• No travel inby unsupported top</li><li>• Crosscuts may only be turned out of specified entries</li><li>• Mined areas must be bolted within specified time</li></ul>	<ul style="list-style-type: none"><li>• Time-weighted average dust exposure limits must not be exceeded</li><li>• Roof bolter can be downwind of CM for only two cuts/shift</li></ul>
Operational	<ul style="list-style-type: none"><li>• Maintain a buffer between bolting and mining functions</li><li>• Mining cannot occur when bolter blocks haulage path</li></ul>	<ul style="list-style-type: none"><li>• Start crosscuts head-on and mine in the direction of ventilation airflow whenever possible</li><li>• Do not mine entry that is deep enough for mining crosscut</li></ul>

# Dynamic Programming

## Examples of constraints and boundary conditions



- Room-and-pillar mining has obvious geometric constraints, i.e. Cut #5 cannot be mined until Cut #1 and Cut #3 have been mined.
- Safety regulations dictate other clear constraints, i.e. Cut #1 and Cut #3 must also be bolted before Cut #5 can be mined.

# Dynamic Programming

- ❖ **The optimal value function (OVF) scores feasible states in terms of certain evaluation criteria**
  - **Productivity**
  - **Cycle time**
  - **Dust exposure**
- ❖ **The recurrence relation is used to select the feasible state with the maximum or minimum score, depending on the objective function, i.e.**
  - **Maximize production**
  - **Minimize cycle time**
  - **Minimize dust exposure**



# Dynamic Programming Algorithm

## **Overall Methodology:**

- **Develop algorithm to quantify the production process**
- **Use algorithm for selection of cuts**

## **Strategic Planning versus Tactical Planning**

# **Dynamic Programming Algorithm**

## **Guiding Policies and Practices**

- **Complete crosscuts in a timely fashion**
- **Maximize starting crosscuts head-on**
- **Mine crosscuts in the direction of ventilation air flow**
- **Maximize double cutting**
- **Maintain buffer between continuous miner and roof bolter**
- **Repeatable sequence for each crosscut of advance**

# Dynamic Programming Algorithm

## Optimal Value Function

**$f_i(X)$  = minimum total  $CCT_i(X)$  that results from following an optimal policy for stage  $i$  given state  $X$**

**where**

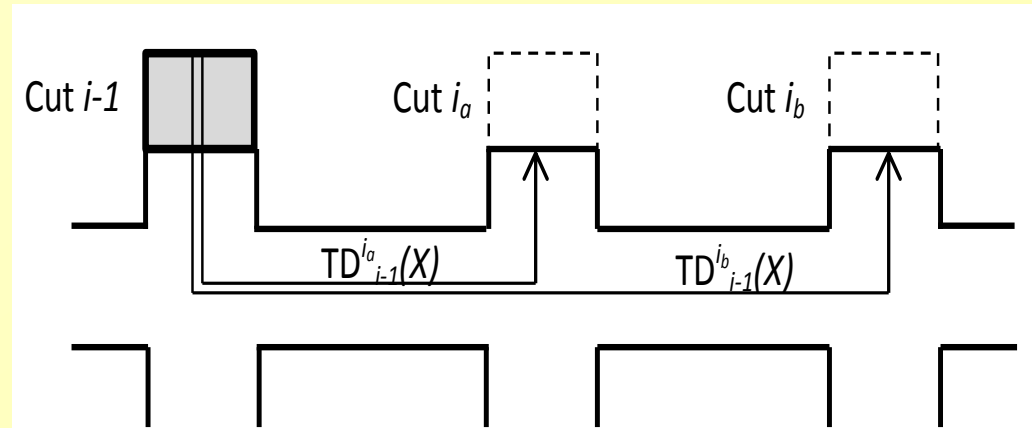
**$CCT_i(X)$  = cut cycle time for stage  $i$  given state  $X$   
=  $MOVE_{i-1}^i(X) + PROD_i(X)$**

**and  $MOVE_{i-1}^i(X)$  = the place change element of  $CCT_i(X)$  from stage  $i-1$  to stage  $i$  in state  $X$**

**$PROD_i(X)$  = the production element of  $CCT_i(X)$  for stage  $i$  given state  $X$**

# Dynamic Programming Algorithm

## Place Change Element



## Parameters

$TD_{i-1}^i(X)$  = tram distance from stage  $i-1$  to stage  $i$  given state  $X$   
 $SPD_{CM}$  = CM tram speed

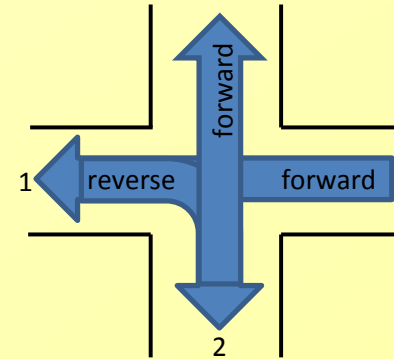
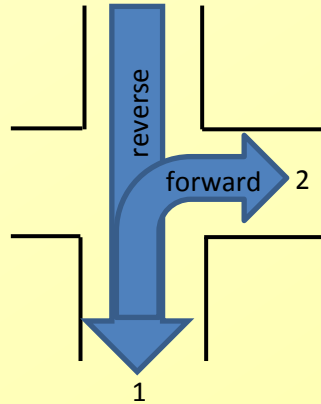
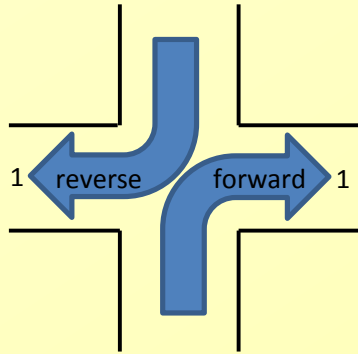
## Basic Time Value for Place Change Element

$$TD_{i-1}^i(X) / SPD_{CM}$$

# Dynamic Programming Algorithm

## Adjustments to Place Change Element Basic Time Value

### ● Cornering Adjustment Factor: $TCOR_{i-1}^i(X)$



$$TCOR_{i-1}^i(X) = [NUMCOR_{i-1}^i(X) * CORTM_{CM}] + [NUMDRCH_{i-1}^i(X) * DRCHTM_{CM}]$$

where  $NUMCOR_{i-1}^i(X)$  = number of corners negotiated moving from stage  $i-1$  to stage  $i$  given state  $X$

$CORTM_{CM}$  = extra time required for CM to negotiate a corner

$NUMDRCH_{i-1}^i(X)$  = number of times CM reverses direction in negotiating corners while moving from stage  $i-1$  to stage  $i$  given state  $X$

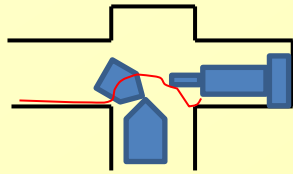
$DRCHTM_{CM}$  = extra time required when CM reverses direction



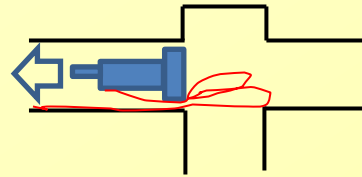
# Dynamic Programming Algorithm

## Adjustments to Place Change Element Basic Time Value

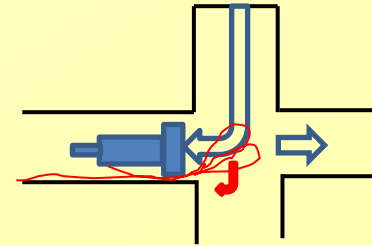
### ● Cable Handling Adjustment Factor: $CH^i_{i-1}(X)$



HANGTM<sub>CM</sub>



HOOKTM<sub>CM</sub>



HANDTM<sub>CM</sub>

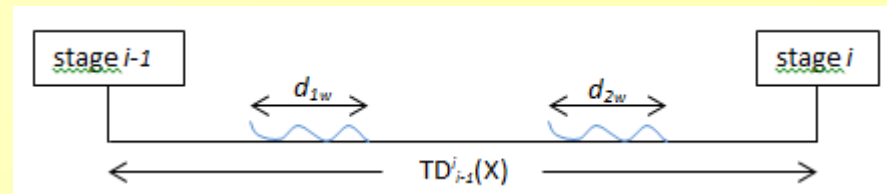
$$\begin{aligned} CH^i_{i-1}(X) = & [NUMHANG^i_{i-1}(X) * HANGTM_{CM}] \\ & + [NUMHOOK^i_{i-1}(X) * HOOKTM_{CM}] \\ & + [NUMHAND^i_{i-1}(X) * HANDTM_{CM}] \end{aligned}$$

# Dynamic Programming Algorithm

## Adjustments to Place Change Element Basic Time Value

### ● Road Condition Adjustment Factor: $\text{RDCON}^i_{i-1}(X)$

- Water
- Soft roads
- Bad top



$$(d_{1w} + d_{2w}) = \text{WATER}^i_{i-1}(X)$$

$$\begin{aligned} \text{RDCON}^i_{i-1}(X) = & [\text{WATER}^i_{i-1}(X) / \text{WATERSPD}_{\text{CM}}] - [\text{WATER}^i_{i-1}(X) / \text{SPD}_{\text{CM}}] \\ & + [\text{SOFTBT}^i_{i-1}(X) / \text{SOFTBTSPD}_{\text{CM}}] - [\text{SOFTBT}^i_{i-1}(X) / \text{SPD}_{\text{CM}}] \\ & + [\text{BDTOP}^i_{i-1}(X) / \text{BDTOPSPD}_{\text{CM}}] - [\text{BDTOP}^i_{i-1}(X) / \text{SPD}_{\text{CM}}] \end{aligned}$$

# Dynamic Programming Algorithm

## Production Element

### 2 Components

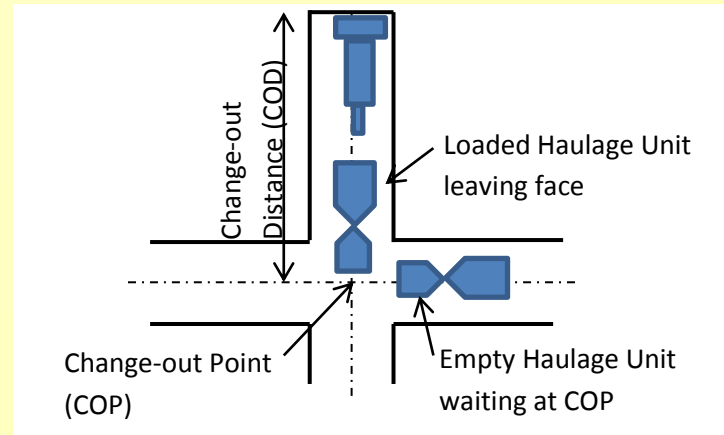
- $COT_i(X)$  = change out time for stage  $i$  given state  $X$
- $LT_i(X)$  = loading time for stage  $i$  given state  $X$

### Basic Time Value for Production Element

$$PROD_i(X) = COT_i(X) + LT_i(X)$$

# Dynamic Programming Algorithm

## Production Element – Change-out Time Component



## Parameters

- $COD_i(X)$  = change-out distance for stage  $i$  given state  $X$   
 $SPD_{HU}$  = haulage unit tram speed  
 $TRIPS_i(X) = \text{ROUNDUP} [CUTVOL_i(X) / (PLD_{HU} * FILL)]$   
 $SWIN$  = haulage unit turn-around (switch in) time at COP

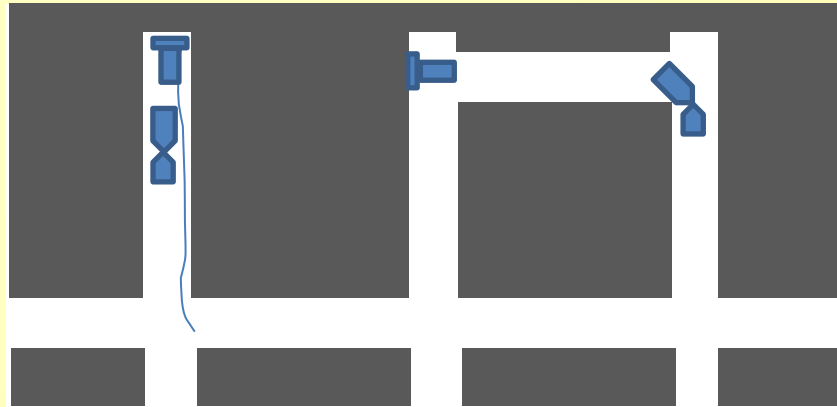
## Basic Time Value for Change-out Time Component

$$COT_i(X) = \{[2 * COD_i(X) / SPD_{HU}] + SWIN\} * TRIPS_i(X)$$

# Dynamic Programming Algorithm

## Adjustments to Production Element Change-out Time Component

### Change-out Condition Adjustment Factor: $\text{COCON}_i(X)$



$\text{COCON}_i(X) = 1.0$  if CO path is unobstructed by hanging line curtain, corners that must be negotiated, and/or poor road conditions  
= 1.5 if CO path is obstructed by one of the above conditions  
= 2.0 if CO path is obstructed by two of the above conditions

$$\text{COT}_i(X) = \{ \{ 2 * \text{COD}_i(X) / [\text{SPD}_{\text{HU}} / \text{COCON}_i(X)] \} + \text{SWIN} \} * \text{TRIPS}_i(X)$$



# Dynamic Programming Algorithm

## Adjustments to Production Element Change-out Time Component

### Wait-on-Car Adjustment Factor: $WOC_i(X)$

$$\begin{aligned} WOC_i(X) = & \{ (2/SPD_{HU}) * \{ HD - [NCARS_i(X) - 1] * COD_i(X) \} \\ & + \{ PLD/DR_{HU} * [3 - 2 * NCARS_i(X)] \} \\ & + \{ SWIN * [2 - NCARS_i(X)] \} \} \\ & * \mathbf{TRUNC}(TRIPS/NCARS) \end{aligned}$$

$$\begin{aligned} & \mathbf{COT}_i(X) = \\ & \{ \{ \{ 2 * COD_i(X) / [SPD_{HU} / COCON_i(X)] \} + SWIN \} * TRIPS_i(X) \} + WOC_i(X) \end{aligned}$$

# Dynamic Programming Algorithm

## Production Element – Loading Time Component

### Parameters

$CUTVOL_i(X)$  = volume of coal in stage  $i$  given state  $X$   
=  $DEPTH_i(X) * WIDTH_i(X) * HEIGHT_i(X) * RCDEN$

$WIDTH_i(X) * HEIGHT_i(X) * RCDEN$  = constant  
= tons/foot of advance (TFA)

$LR_{CM}$  = CM loading rate

## Basic Time Value for Loading Time Component

$$LT_i(X) = \{ [TFA * DEPTH_i(X)] / LR_{CM} \}$$

# Dynamic Programming Algorithm

## Adjustment to Production Element Loading Time Component

- Clean-up Adjustment Factor:  $WOC_i(X)$

$RESET_{HU}$  = haulage unit reset during cleanup passes

$$LT_i(X) = \{[TFA * DEPTH_i(X)] / LR_{CM}\} + RESET_{HU}$$

# Application Case Study

## Constraint Matrix

	Bolting	Ventilation
Regulatory	<ul style="list-style-type: none"><li>• No travel inby unsupported top</li><li>• Turn crosscuts only out of #3, #4, #8, and #9 Entries</li><li>• Mined areas must be bolted within specified time</li></ul>	<ul style="list-style-type: none"><li>• Time-weighted average dust exposure limits must not be exceeded</li><li>• Roof bolter can be downwind of CM for only two cuts/shift</li></ul>
Operational	<ul style="list-style-type: none"><li>• Maintain a buffer between bolting and mining functions</li><li>• Mining cannot occur when bolter blocks haulage path</li></ul>	<ul style="list-style-type: none"><li>• Start crosscuts head-on and mine in the direction of ventilation airflow whenever possible</li><li>• Do not mine entry that is deep enough for mining crosscut</li></ul>

# Application Case Study

## Iterations

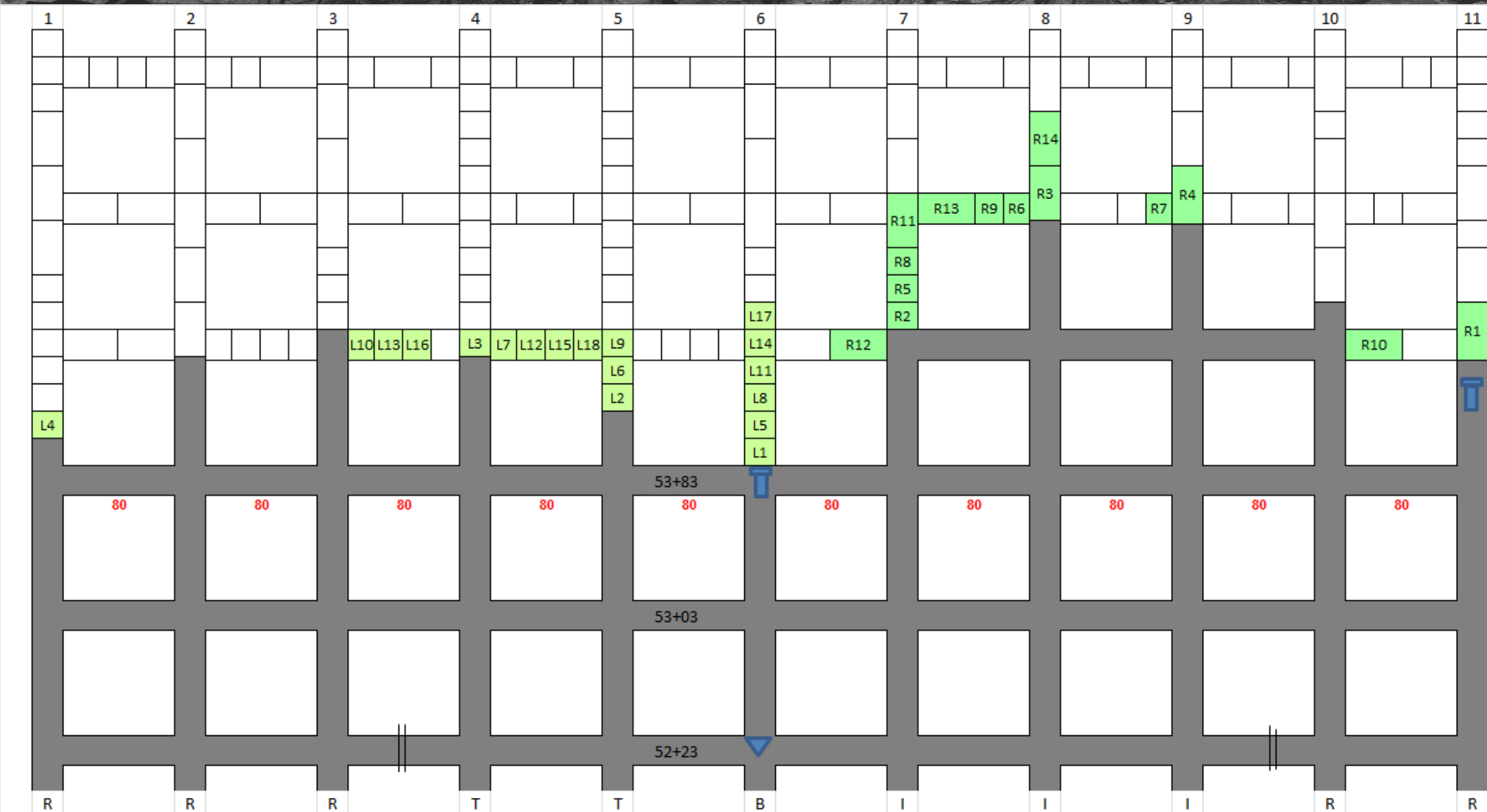
				#1 Entry	#2 Entry	#3 Entry	#4 Entry	#5 Entry	#6 Entry
Cuts Available for 4th Cut				E1.1	E2.1	E3.1 C34.1	E4.2 C45.1	E5.2	E6.2
Constraint - bolt, vent, both						vent	both bolt	bolt	
Corner/Curtain Factor				1	1.5	1.5			1.5
HD				480	480	400			240
COD				99	84	89			104
WOC Factor				0.84	3.04	-0.10			-2.99
DEPTH				10	30	20			10
OSD				30	6	6			18
TRIPS - number of loads				10	21	14			9
CO Segment				7.87	20.69	12.30			8.94
Loading Segment				9.50	18.62	19.13			8.31
Production Element				17.37	39.31	31.43			17.25
Number of Corners				2	2	3			2
Direction Changes				1	1	1			1
Cable Hook-ons				4	4	3			3
Cable Handling				0	0	0			2
TD				345	330	255			270
Place Change Element				8.21	8.01	7.44			10.99
DP Model CCT Value				25.58	47.32	38.87			28.24



# Recursive Paths

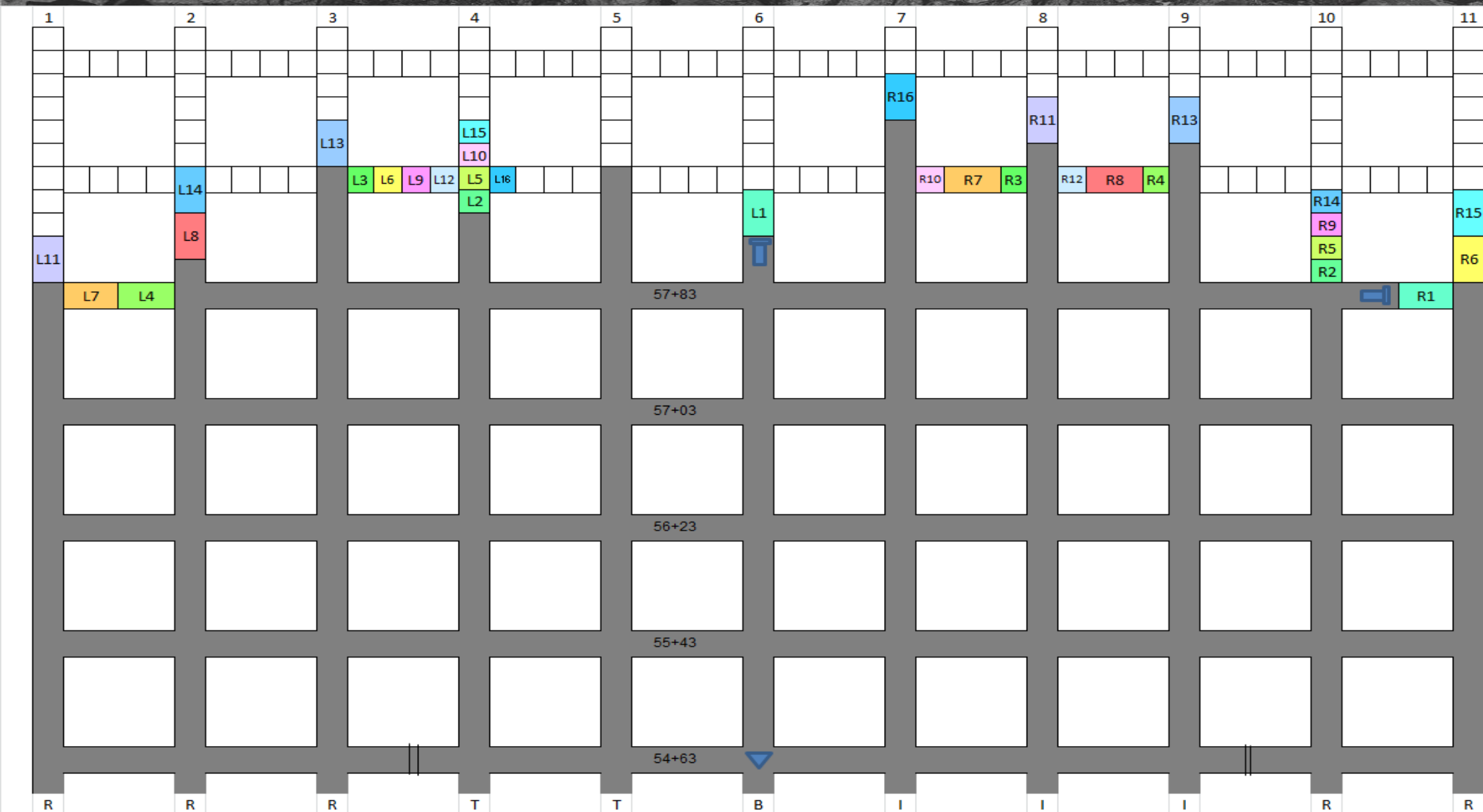
Path										
1st Cut Options										
Optimal value $CCT_i(X)$	E6.1 16.53									
2nd Cut Options										
Optimal value $CCT_i(X)$	E4.1 28.99									
$f_i(X)$	45.51									
3rd Cut Options										
Optimal value $CCT_i(X)$	E1.1 28.55	E5.1 29.49		E4.1 26.18						
$f_i(X)$	74.07	75.00		71.36						
4th Cut Options										
Optimal value $CCT_i(X)$	E6.2 26.05	E6.2 26.81		E1.1 28.55		E6.2 28.24				
$f_i(X)$	100.12	101.81		99.91		99.60				
5th Cut Options										
Optimal value $CCT_i(X)$	E5.1 28.79	E1.1 32.44		E5.2 26.40		E6.2 26.05		E5.2 21.99		
$f_i(X)$	128.91	134.25		126.31		125.96		121.59		
6th Cut Options										
Optimal value $CCT_i(X)$	C45.1 32.46	E5.2 26.40		E6.2 26.94		E5.2 20.59		E1.1 29.63		
$f_i(X)$	161.36	160.65		153.26		146.55		151.22		
7th Cut Options										
Optimal value $CCT_i(X)$	E6.3 36.70	C45.1 32.59		C45.1 35.40		C45.1 32.59		E6.3 33.47		
$f_i(X)$	198.07	193.25		188.66		179.14		184.68		
8th Cut Options										
Optimal value $CCT_i(X)$	E5.2 22.83	E6.3 36.70		E5.3 39.01		E6.3 36.70		C45.1 35.65		
$f_i(X)$	220.90	229.95		227.67		215.85		220.33		
9th Cut Options										
Optimal value $CCT_i(X)$	C34.1 43.06	E5.3 37.71		E6.3 34.63		E5.3 37.71		E5.3 39.01		
$f_i(X)$	263.95	267.67		262.29		253.56		259.34		
10th Cut Options										
Optimal value $CCT_i(X)$	E6.4 32.79	C34.1 43.32		C34.1 46.11		C34.1 43.32		E6.4 29.29		
$f_i(X)$	296.74	310.99		308.40		296.88		288.62		
11th Cut Options										
Optimal value $CCT_i(X)$	E5.3 37.88	E6.4 32.79		E1.2 49.39		C45.2 49.69		C34.1 46.27		
$f_i(X)$	334.62	343.78		357.79		358.09		334.89		
12th Cut Options										
Optimal value $CCT_i(X)$	E1.2 46.06	C45.2 46.77	C45.2 49.72	E6.4 28.39	E6.4 26.10	C45.2 49.72	C45.2 49.69	E1.2 49.39		
$f_i(X)$	380.67	381.39	393.50	386.18	384.19	379.39	384.58	384.28		
13th Cut Options										
Optimal value $CCT_i(X)$	C34.2 49.36									
$f_i(X)$	428.75									
14th Cut Options										
Optimal value $CCT_i(X)$	E6.5 32.60									
$f_i(X)$	461.35									
15th Cut Options										
Optimal value $CCT_i(X)$	C45.3 52.88									
$f_i(X)$	514.24									

# Application Case Study

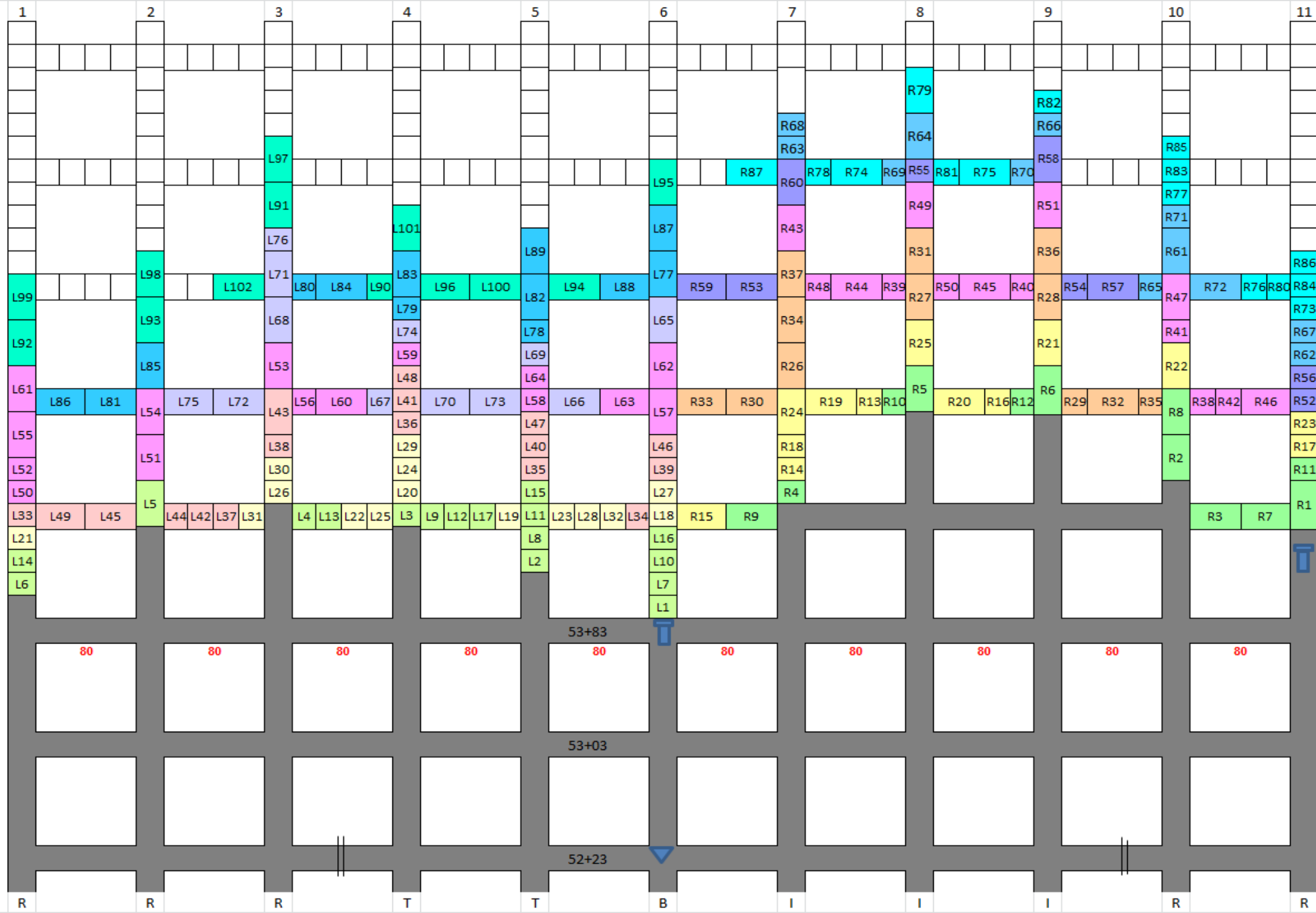


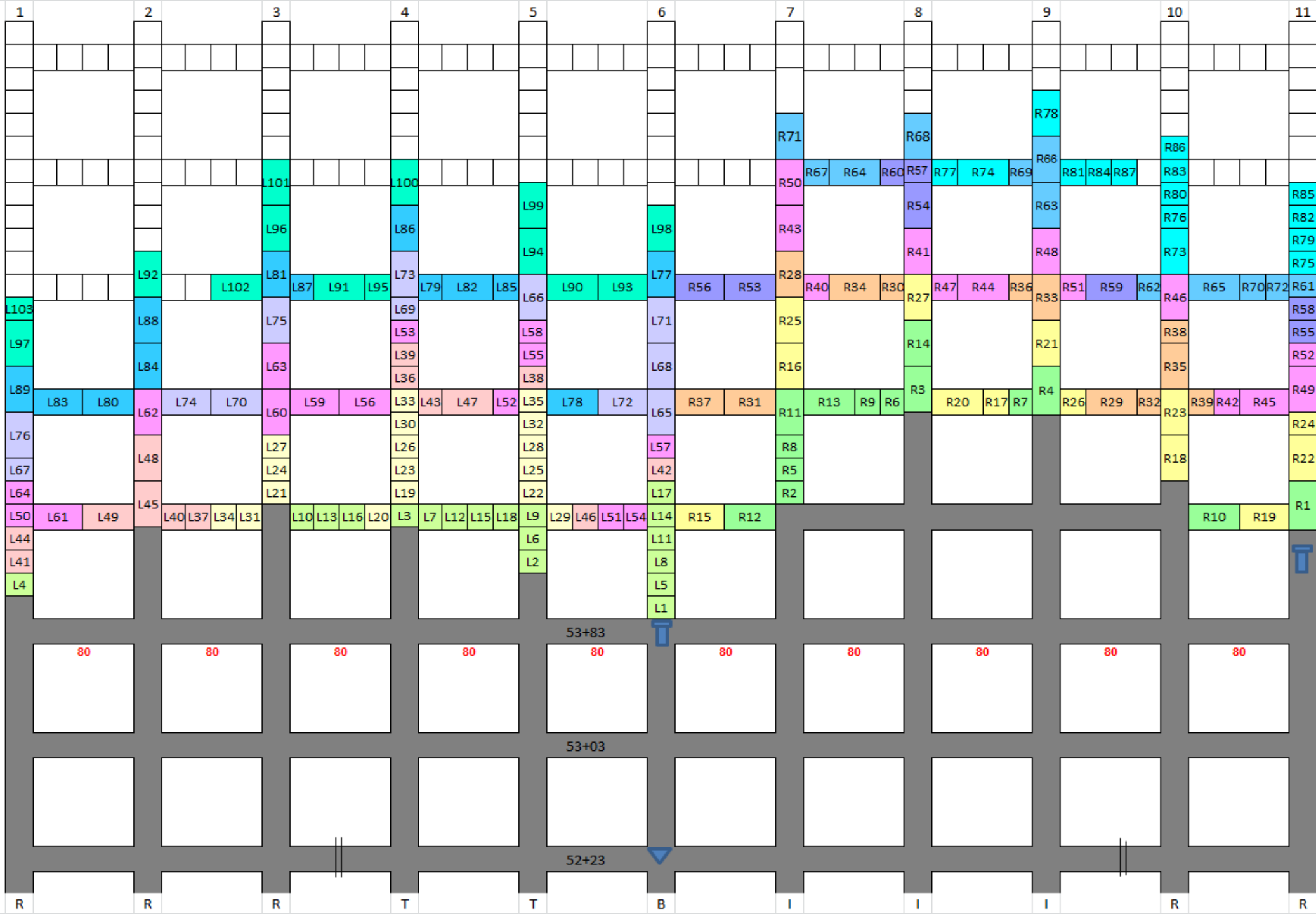
**Predicted Actual Optimal Minimum Sequence for Day 1**

# Application Case Study



**Predicted Actual Optimal Minimum Sequence for Day 1 Day 12**







# Application Case Study

Day	AMS			OMS			Difference		
	Cuts	Feet Mined	CCT (min)	Cuts	Feet Mined	CCT (min)	Cuts	Feet Mined	CCT (min)
1	17	276	590	18	252	596	+1	-24	+6
2	15	221	508	17	229	503	+2	+8	-5
3	17	292	521	14	285	538	-3	-7	+17
4	15	375	662	15	384	624	0	+9	-38
5	12	343	600	12	375	598	0	+32	-2
6	13	384	612	13	357	610	0	-27	-2
7	13	394	651	14	402	675	+1	+8	+24
Totals	102	2285	4144	103	2284	4144	+1	-1	0

**Left-side CM**

**Right-side CM**

Day	AMS			OMS			Difference		
	Cuts	Feet Mined	CCT (min)	Cuts	Feet Mined	CCT (min)	Cuts	Feet Mined	CCT (min)
1	12	314	544	14	348	556	+2	+34	+12
2	13	353	601	13	365	606	0	+12	+5
3	12	336	554	12	297	533	0	-39	-21
4	14	329	638	13	355	635	-1	+26	-3
5	9	245	419	8	214	415	-1	-31	-4
6	12	292	544	12	282	552	0	-10	+8
7	15	273	590	15	255	590	0	-18	0
Totals	87	2142	3890	87	2116	3887	0	-26	-3

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&



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**Lively Grove Mine**

## QUESTIONS

on

## Identifying Optimal Mining Sequences for Continuous Miner

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