QUARRY SCHEDULING OPTIMIZATION AND SMART QUARRY MONITORING THROUGH AI

(Dr. Puneet Nigam)
HOLTEC CONSULTING

WEBINAR FLOW

01 General

02 Computer Aided Deposit Evaluation (CADE)

03 Quarry Scheduling Optimization (QSO)

04 Predictive v/s Actual Quality analysis

05 Block Model updation

06 Remote Quarry Monitoring through AI

07 Cost Analysis

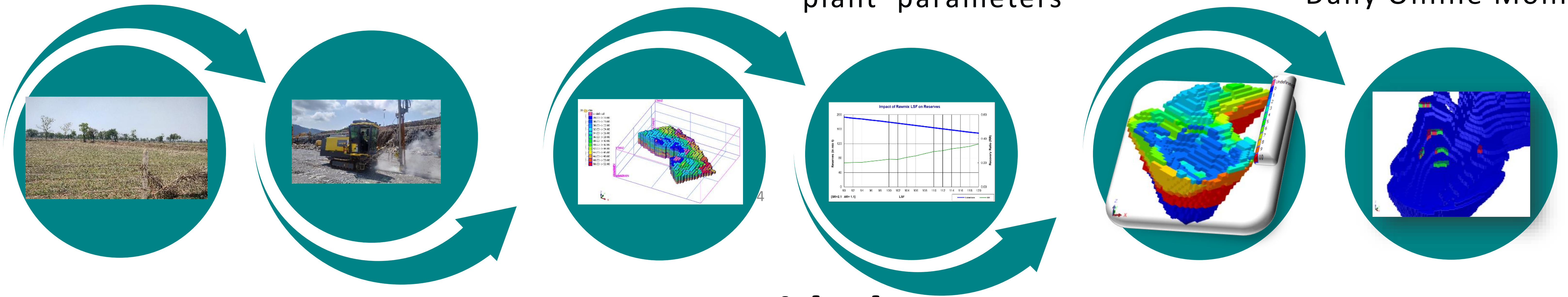
GENERAL - LIMESTONE FOR CEMENT INDUSTRY

Non Renewable Resources given by nature

Specific Quality Requirement in LSF, SM, AM or other minor radicals

Require Strategic Planner by blending of different grade with minimum deviation

STEPS FOR DEPOSIT EVALUATION



Site Identification
Reconnaissance Survey
Selection of potential area

Exploration
General investigation
Detail investigation

Computer Aided Deposit Model
Conceptualized deposit behaviour
Reserves Assessment

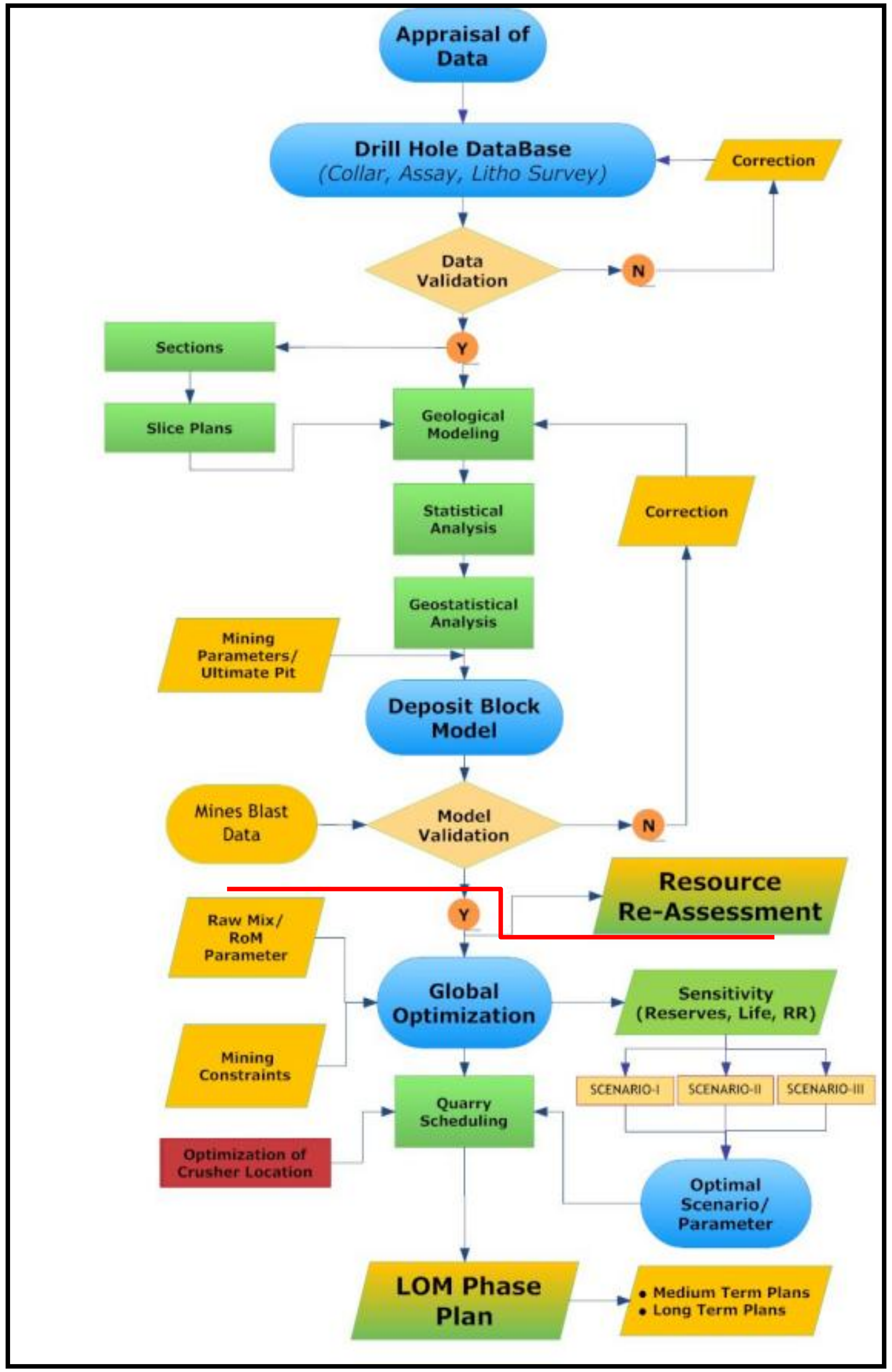
Deposit Optimization
Finalization of Sensitive plant parameters

Quarry scheduling
Long Term
Short Term

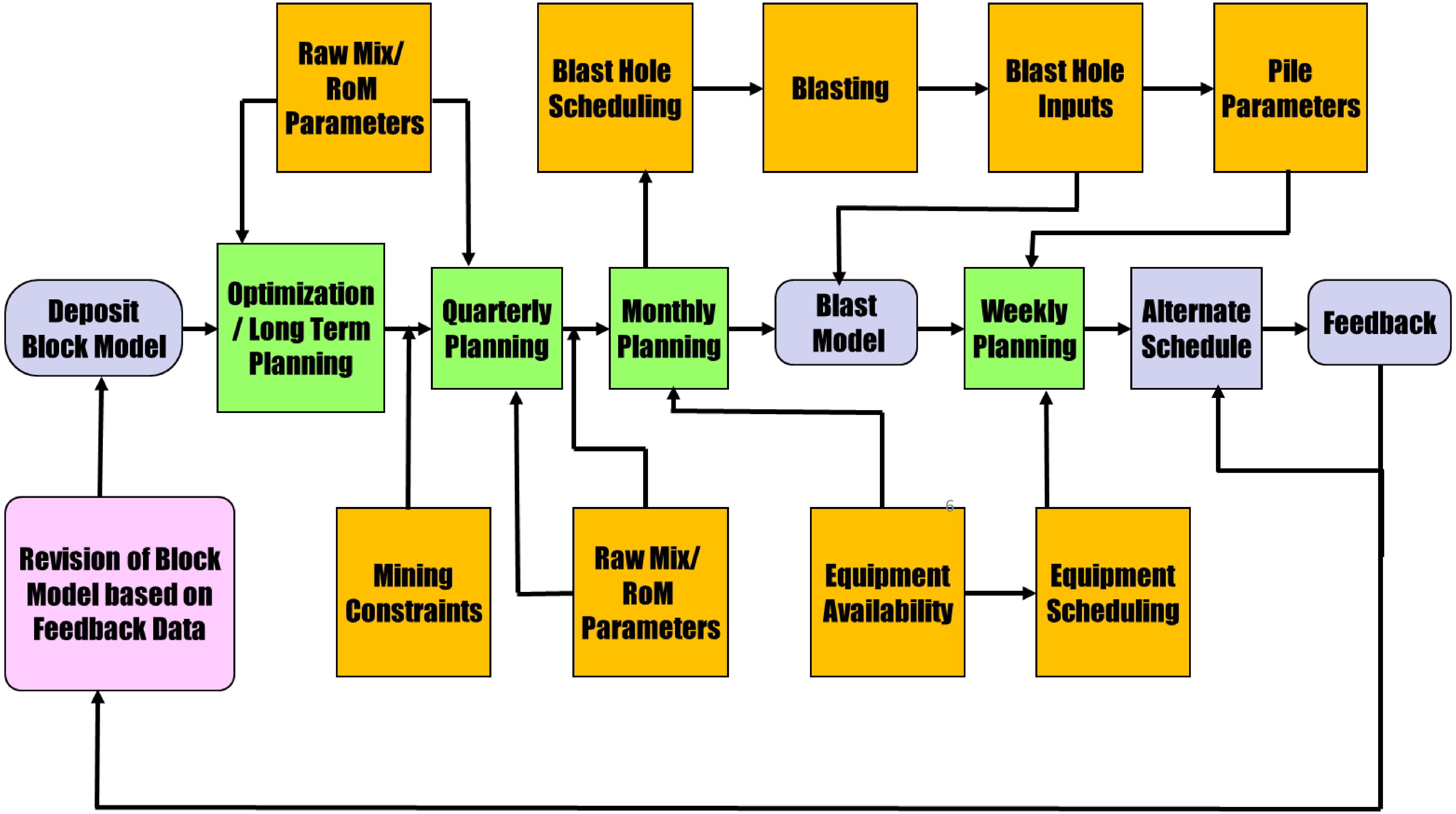
Validation of Model
Estimated vs Actual
Daily Online Monitoring by AI

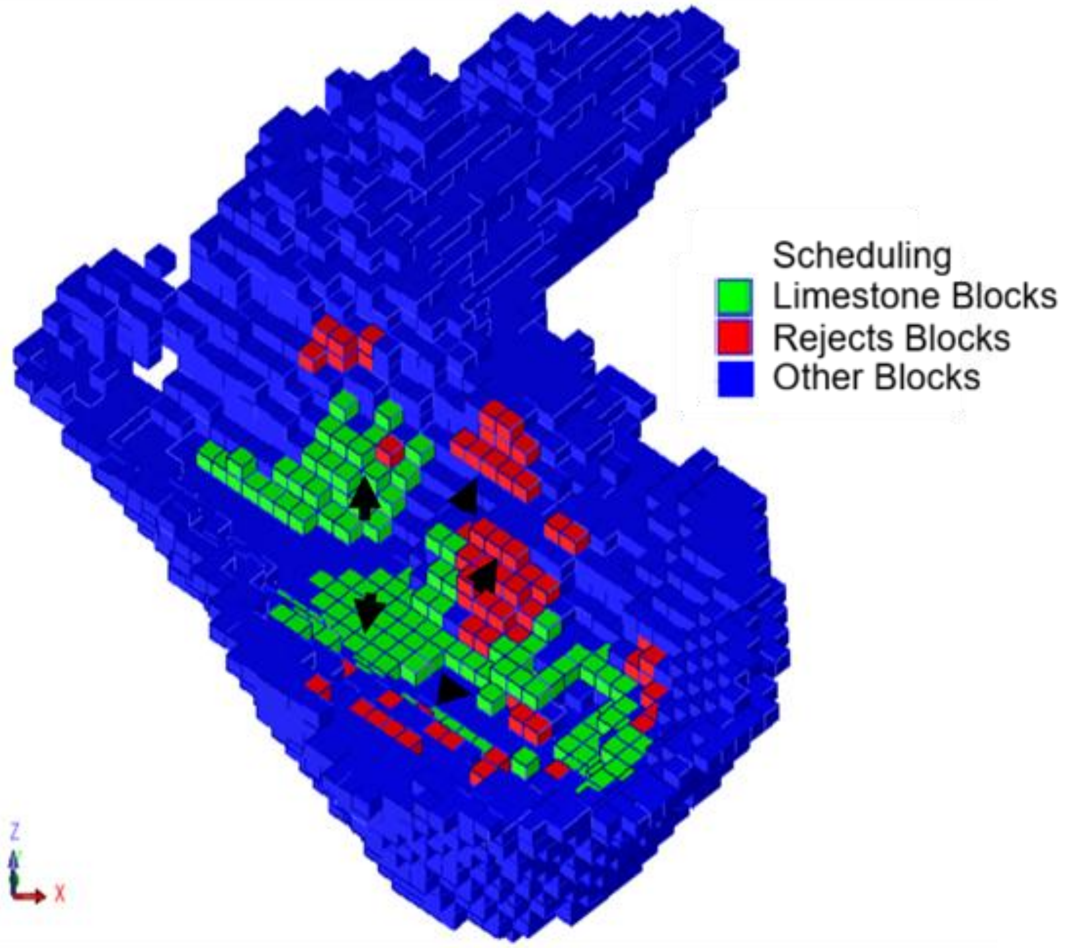
CADE AND QSO – FLOW CHART

- ❑ Drill hole Database
- ❑ Geological Cross Sections
- ❑ Geological Modeling
- ❑ Digital Terrain Modeling
- ❑ Statistical/ Geo-statistical Modeling
- ❑ Block Modeling
- ❑ Resource/ Reserves Classification
- ❑ Grade Tonnage study
- ❑ Mineable Reserves and Quality
- ❑ Optimization and Sensitivity
- ❑ Selection of Optimal Parameter
- ❑ Global Optimized Reserves
- ❑ Periodic Updation of Block Model with Blast hole data
- ❑ Quarry Monitoring through AI

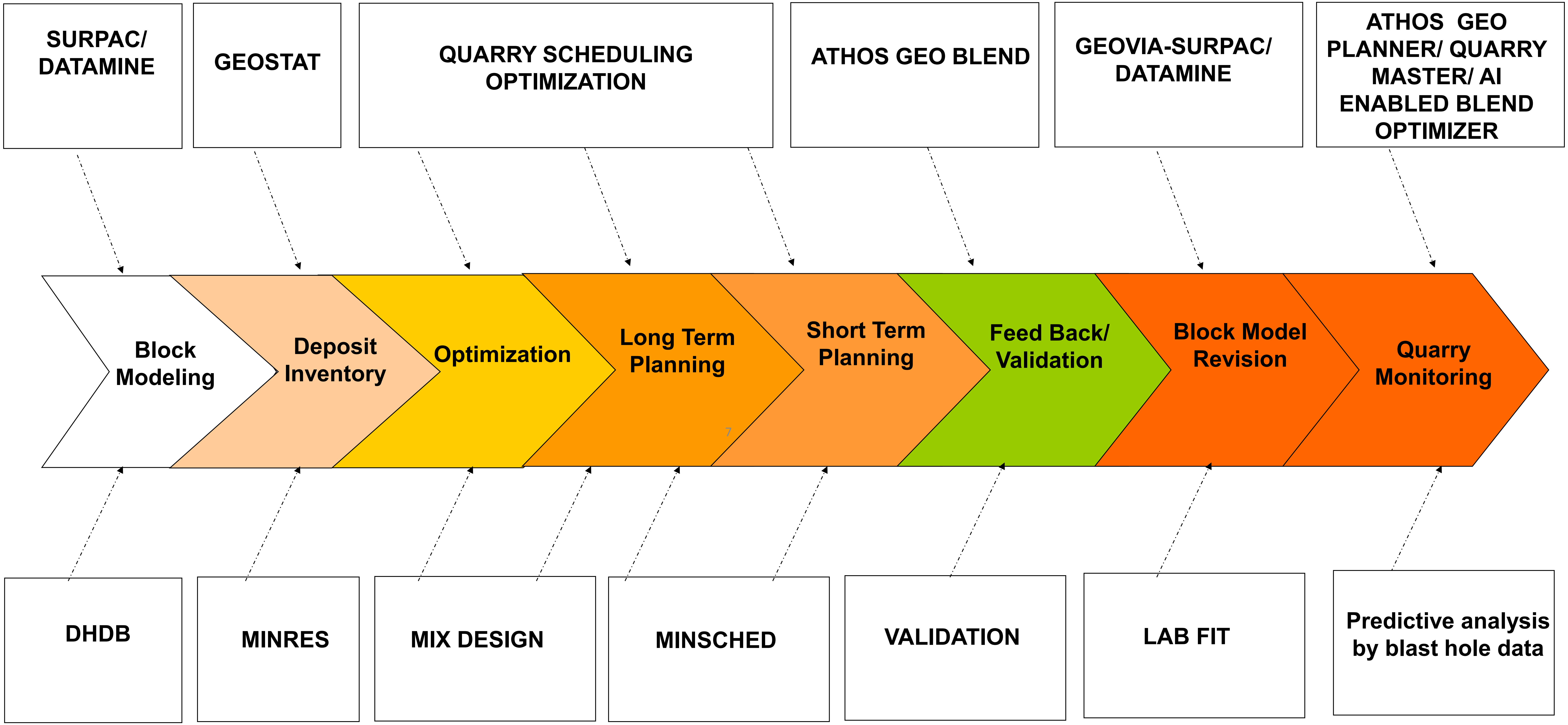


QSO - METHODOLOGY





QSO - TOOLS


SURPAC/ DATAMINE
GEOSTAT
QUARRY SCHEDULING OPTIMIZATION
ATHOS GEO BLEND
GEOVIA-SURPAC/ DATAMINE
ATHOS GEO PLANNER/ QUARRY MASTER/ AI ENABLED BLEND OPTIMIZER
Block Modeling
Deposit Inventory
Optimization
Long Term Planning
Short Term Planning
Feed Back/ Validation
Block Model Revision
Quarry Monitoring
DHDB
MINRES
MIX DESIGN
MINSCHED
VALIDATION
LAB FIT
Predictive analysis by blast hole data

QUARRY CONCEPTS

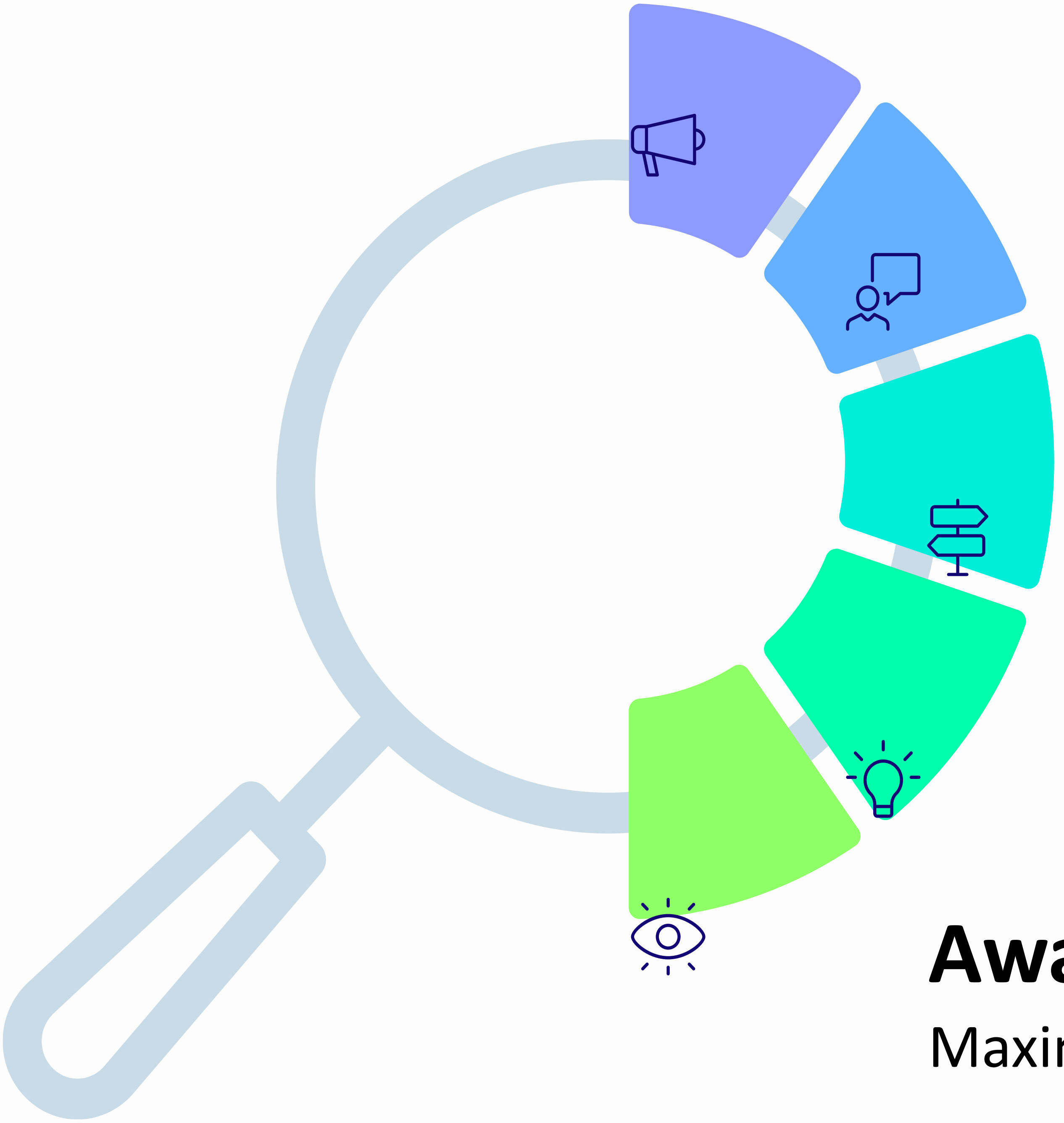
Optimal Scheduling for non-renewable Resource Extraction

Regular and continuous updation of deposit inventory on short term basis

Steady supply of homogenized Material

Use of real time data analysis and advance analysis

QUARRY MANAGEMENT



Vision Setting for Mines and Plant Personal

Stable clinker production process with maximum production and minimum production cost

Environment Friendly

Emission control from the source through controlling minor elements in rawmix

Coordination between Mines and Plant

Reduce corrective consumption means lower production cost

Decision Making

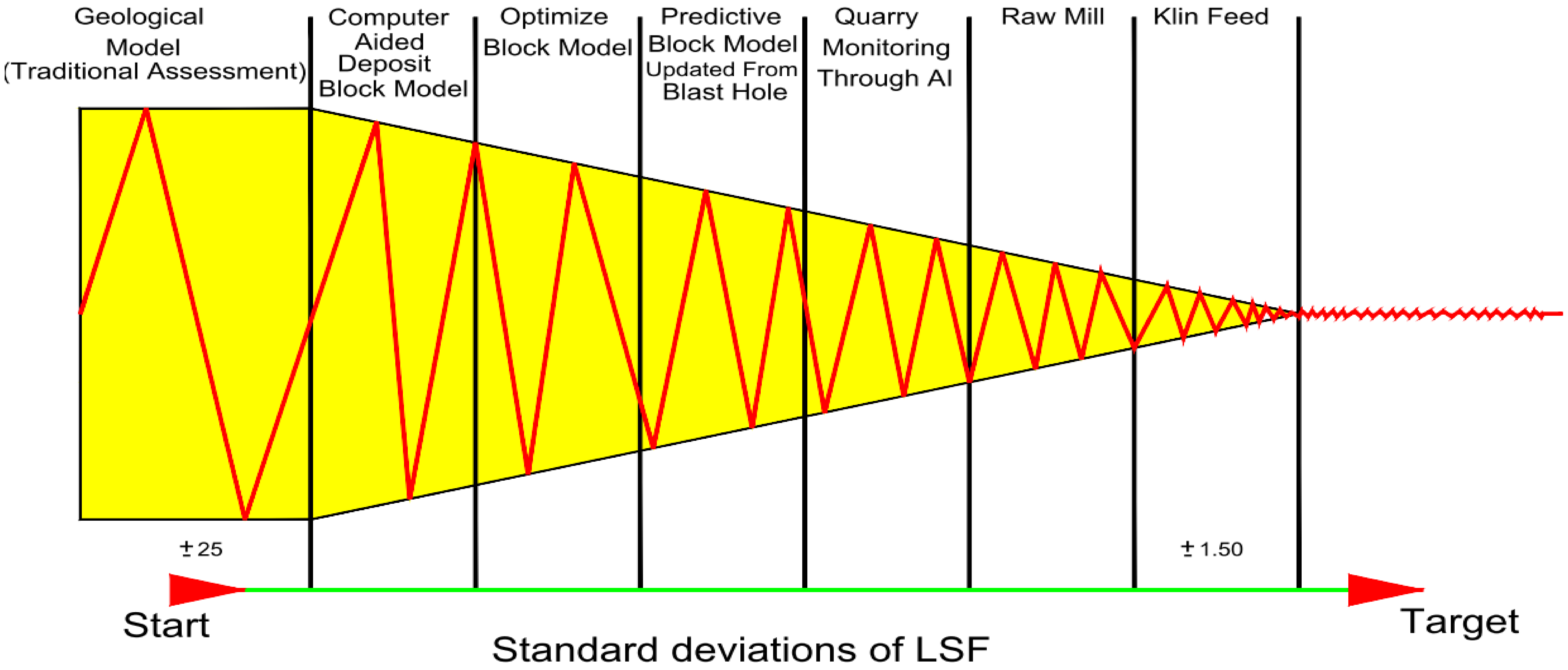
Optimized quarry operation with quality control from the source and minimum wasting

Awareness

Maximize quarry lifetime through judicious blending

OBJECTIVE TO MINIMISE QUALITY DEVIATION

Reduction in Quality Deviation from Quarry to Raw Mill



INFLUENCING FACTORS

Change in Quality of Limestone

Change in availability of Mining Equipment

Dynamic or Specific response to issue

Change in Fuel types

Availability and Quality of Correctives

REMOTE QUARRY MONITORING - WHY

Cost-efficient solution to dynamically optimize mine operations

01

Inaccuracies caused by wider grid spacing initially employed

02

Unexpected occurrences of deleterious material and physical constraints

03

Changes in environmental statute and quality variations in input materials and product requirements

04

Ease of mining considerations of Mines Manager

05

Inadequacy of local expertise (manpower, analytical tools, etc.)

06

O&M contracts which ignore resource conservation

WHAT DOES REMOTE QUARRY MONITORING ACHIEVE

01 Monitoring of mining operations on dynamic basis (weekly/ fortnightly/ monthly/ daily/ pile wise)

02 Allows flexibility in mining operations by dynamically optimizing extraction plans

03 Assures steady supply of homogenized material to meet changing quality requirements

04 Minimizes human dependency and bias

05 Savings in mining cost

06 Most importantly, extends deposit life

SMART STRATEGIES

01

Specific desired scheduling with long term objective

02

Measurable mining cost viz overburden handling, equipment etc.

03

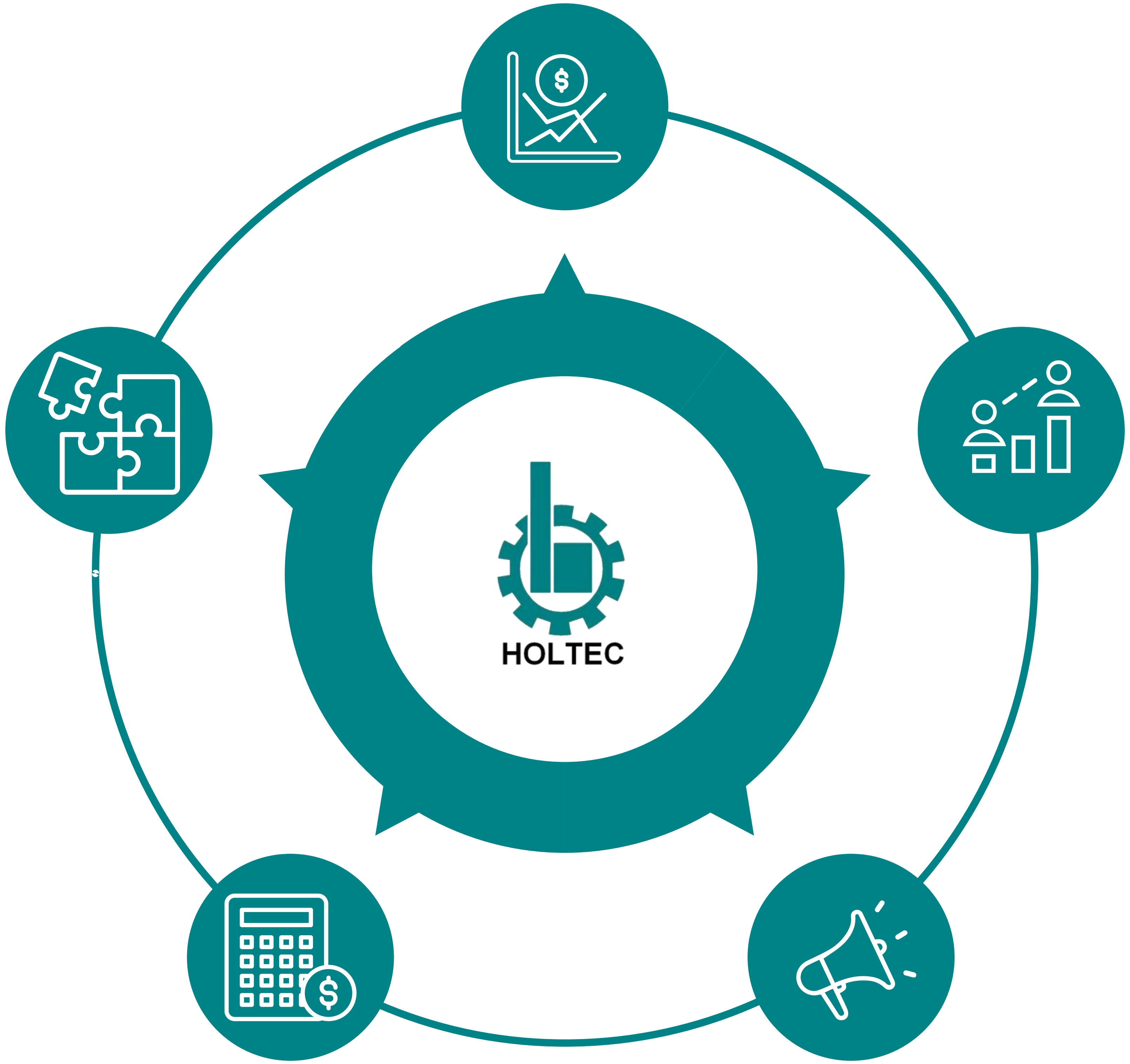
Alternative approach

04

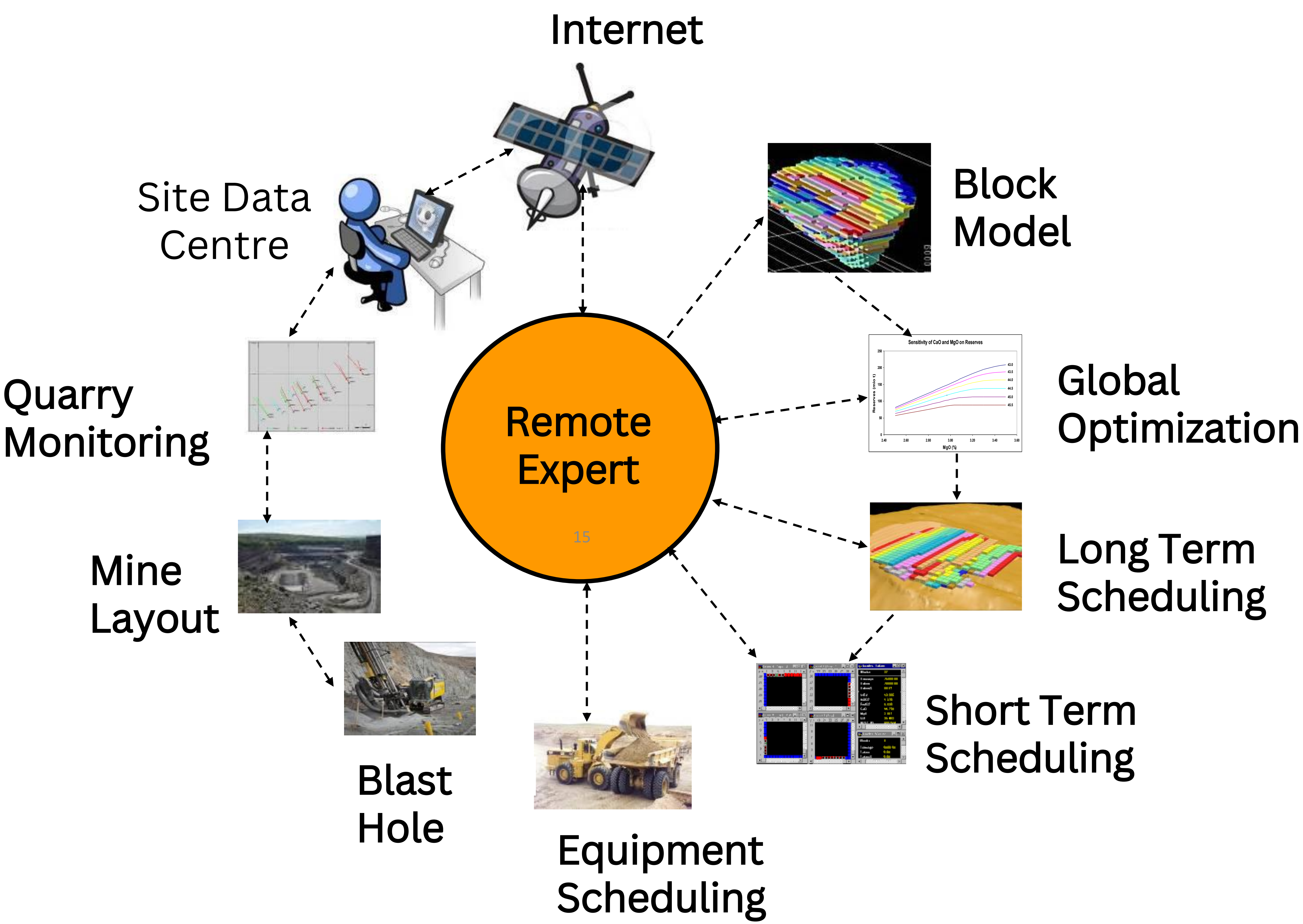
Required Run-of-Mine and Rawmix quality

05

Time management to achieve desired goal like pile formation



SYSTEM – REMOTE MONITORING

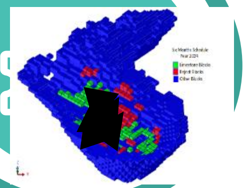


PREDICTIVE QUALITY ASSURANCE

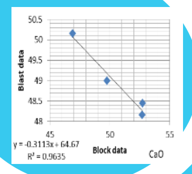
Evaluation

01 Reliably predict the quality of crusher feed/ pre-blending input

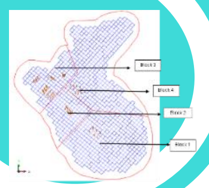
02 Both long term and short-term block models would be revalidated



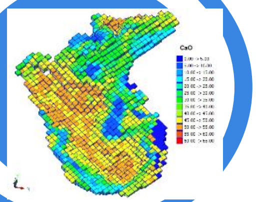
03 Comparison of mined blocks with the pre-blending sample



04 Initially all blast hole sample would need to be analyzed



05 Deviation within acceptable limits with feedback data



Predictive Quality Assurance From Mines

Benefits

Increased usable reserves 01

Steady supply of homogeneous kiln feed 02

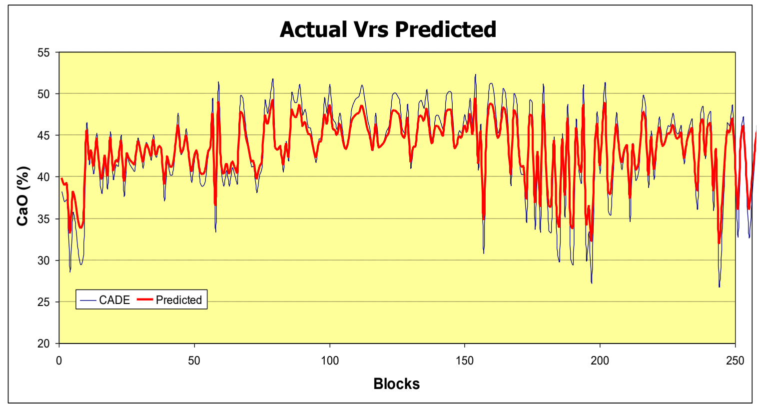
Minimized usable mix cost 03

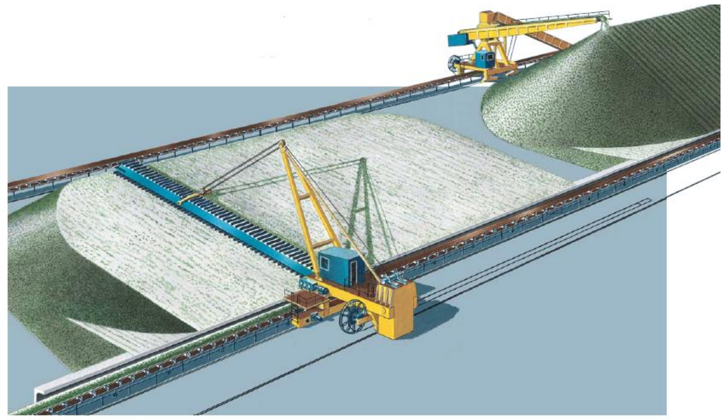
Consistency in products quality 04

Reduced operational problem 05

- Typical payback period 6-12 months of operating cost of PQA
- It is less than the cost of correctives etc. saved on a daily basis

BLOCK MODEL UPDATION
PREDICTIVE V/S ACTUAL QUALITY ANALYSIS

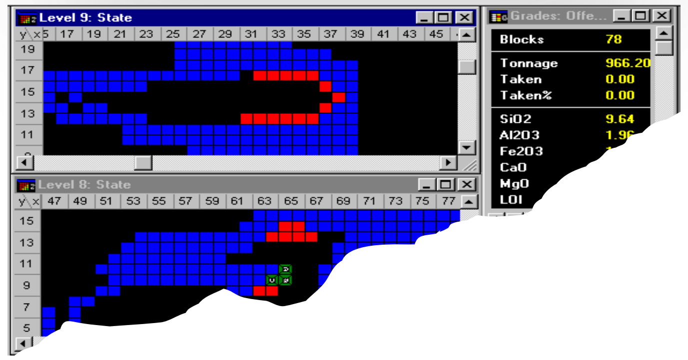




01

Model Validation

Predicted Vs Actual



02

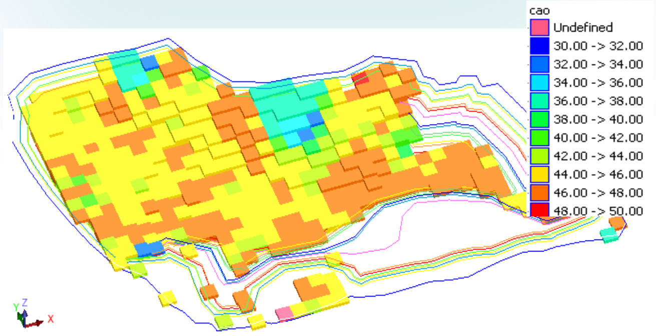
Analysis of Quality variation

17

03

Model Updation

Quality and Quantity updated



04

Pile Formation

Hourly and shift monitoring

REMOTE QUARRY MONITORING THROUGH AI DATA FORMAT

MINE MIX AI

Optimization · Quality Control · Kiln Feed Management

Live Session

DATE OF SAMPLE 2026-03-13 | HOUR 12:00 | PRODUCT Raw Mix

5 Blasts Active · 4 Correctives

TOTAL QUANTITY	RAWMIX LSF	RAWMIX SR	RAWMIX AR	RAWMIX TOTAL
10,000 Th T	98.05	2.38	1.02	99.67 %

Limestone Blast Sample Analysis

Quarry feed composition · Oxide analysis per blast

BLAST	QTY TH T	LOI	SIO_2	AL_2O_3	FE_2O_3	CAO	MGO	NA_2O	K_2O	SO_3	P_2O_5	LSF	SR	AR	TOTAL
Blast 1	80	36.20	12.61	3.01	2.41	41.59	3.25	0.11	0.31	0.03	0.11	102.88	2.33	1.25	99.63
Blast 2	1000	40.33	6.65	1.15	0.34	49.03	1.70	0.12	0.25	0.03	0.10	242.75	4.46	3.38	99.70
Blast 3	200	34.63	19.36	2.67	0.53	38.76	2.94	0.08	0.31	0.00	0.12	67.17	6.05	5.04	99.09
Blast 4	300	39.04	9.24	1.04	0.43	36.43	13.40	0.10	0.13	0.00	0.00	133.06	6.29	2.42	99.81
Blast 5	50	37.51	12.13	2.05	0.88	43.31	3.27	0.10	0.25	0.02	0.09	117.20	4.14	2.33	99.61
Pile ROM	*8979*	*39.58*	*8.24*	*1.22*	*0.38*	*44.72*	*5.14*	*0.11*	*0.20*	*0.02*	*0.07*	*180.58*	*5.16*	*3.22*	*99.69*
Rawmix	**10000**	**36.00**	**12.88**	**2.73**	**2.68**	**40.24**	**4.66**	**0.11**	**0.25**	**0.02**	**0.09**	**98.05**	**2.38**	**1.02**	**99.67**

Correctives

Additive materials for chemistry adjustment

NAME	QTY TH T	LOI	SIO_2	AL_2O_3	FE_2O_3	CAO	MGO	NA_2O	K_2O	SO_3	P_2O_5	LSF	SR	AR	TOTAL
Iron Slag	1.20	2.56	51.42	20.86	23.45	0.83	0.60	0.00	0.00	0.00	0.00	0.45	1.16	0.89	99.72
Clay	2.40	5.03	73.64	12.20	4.75	1.00	0.40	0.11	1.67	0.13	0.43	0.45	4.34	2.57	99.36
Iron Ore	5.40	8.83	12.33	11.93	65.00	0.20	0.20	0.10	0.20	0.04	0.35	0.22	0.16	0.18	99.18
Laterite	6.50	10.98	5.32	36.10	42.96	1.32	0.80	0.00	0.00	0.00	0.00	1.55	0.07	0.84	97.48

RAWMIX LIMITS

Min · Max constraints

PARAM	MIN	MAX
LSF	101.00	103.00
SM	2.20	2.30
AM	1.20	1.40
MgO	2.50	5.00

TARGET RESULT

Optimized quantities · Th T

B1	Blast 1	0.00
B2	Blast 2	58.00
B3	Blast 3	6.00
B4	Blast 4	25.79
B5	Blast 5	0.00
ISL	Iron Slag	4.56
CL	Clay	3.98
IO	Iron Ore	1.67
LT	Laterite	0.00

PREDICT

MINING PROCESS INTELLIGENCE

AI-Enabled Blend Optimizer

AI-Driven Mine Selection & Corrective Additive Dosing for Target LSF · SM · AM or any radicals for Raw Mix Optimization

98.0	2.20	1.10
Target LSF	Target SM	Target AM

SCOPE

Source
5 Mines/Faces + 3 corrective additives

Algorithm
AI based Intelligent system

Output
T/day per source + blend chemistry

Moduli
LSF · SM · AM achieved vs target

Scenarios
Quality mode vs Cost mode
Pile mode vs Raw Mix mode

Sensitivity
Mine chemistry variability analysis

BLEND OPTIMIZER

What We Have vs What We Need

Blasthole Data
5 Mines with known CaO, SiO_2, Al_2O_3, Fe_2O_3 chemistry

Additives
Laterite - Iron Ore - Sand — each corrects a specific oxide

Constraints
Each mine has max T/day availability and min contract tonnage
Face / Mine Selection

Costs
Mining + transport cost varies per source (₹55–₹150/mt)

→ AI OPTIMIZER

Blend Optimizer Output

Mine-1 Calcareous	1,380 T/day	13.8 %
Mine-2 Normal	2,810 T/day	28.1%
Mine-3 Siliceous	2,980 T/day	29.8%
Mine-4 Argillaceous	580 T/day	5.8%
Mine-5 Mixed	1,600 T/day	16.0%
Laterite (additive)	280 T/day	2.8%
Sand (additive)	220 T/day	2.2%
Iron Ore (additive)	150 T/day	1.5%

OPTIMIZER OUTPUT

BLENDED LSF
98.03
Target: 98.0 | ✓ OK

SILICA MODULUS
2.204
Target: 2.20 | ✓ OK

ALUMINA MODULUS
1.183
Target: 1.15 | ▲ Review

C3S POTENTIAL
~56%
Clinker quality | ✓ Good

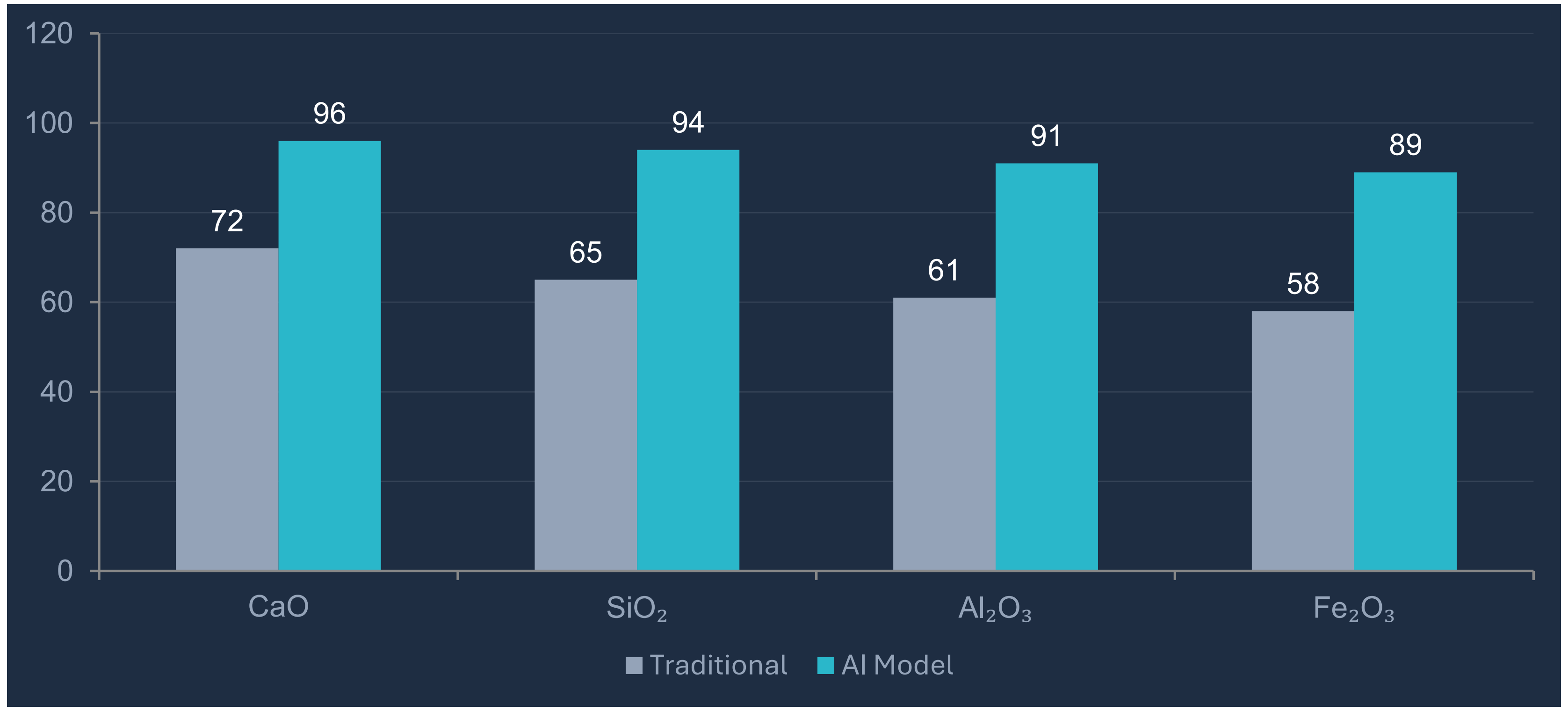
Optimized Mine & Additive Allocation

SOURCE	%	T/DAY
Mine-1 Calcareous	13.8%	1,380
Mine-2 Normal Grade	28.1%	2,810
Mine-3 Siliceous	29.8%	2,980
Mine-4 Argillaceous	5.8%	580
Mine-5 Mixed	16.0%	1,600
Laterite	2.8%	280
Sand / Quartzite	2.2%	220
Iron Ore Fines	1.5%	150

Blended Chemistry

BLENDED FEED CHEMISTRY

42.8%	13.8%	4.1%	2.5%	0.5%	31.2%
CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	LOI



QUALITY vs COST MODE

Quality vs Cost Optimization — Allocation Shift

SOURCE	QUALITY MODE	COST MODE	ΔSHIFT
○ Mine-1 Calcareous	13.8%	9.0%	-4.8%
○ Mine-2 Normal	28.1%	31.0%	+2.9%
○ Mine-3 Siliceous	29.8%	31.0%	+1.2%
○ Mine-4 Argillaceous	5.8%	12.0%	+6.2%
○ Mine-5 Mixed	16.0%	11.5%	-4.5%
○ Laterite	2.8%	2.0%	-0.8%
○ Sand / Quartzite	2.2%	2.5%	-0.5%
○ Iron Ore Fines	1.5%	1.0%	+0.3%

2-5%
Blending Cost Reduction

10-25%
Kiln Feed LSF Standard Deviation ↓

10-15%
Clinker Free Lime Standard Deviation ↓

System Architecture & Implementation

PHASE 1 Month 1–2

Data Foundation

Blasthole XRF database setup · Mine block chemistry averaging · Historical blend record import

PHASE 2 Month 3–4

AI Deployment

Python based engine integration · Daily blend recommendation output · Quality vs Cost Mode toggle

Phase 3 Month 5–6

Closed-Loop Control

DCS/SCADA feed integration · Auto-update mine chemistry shifts · Alert on infeasible blend scenarios

2 – 5% Blending Cost Reduction

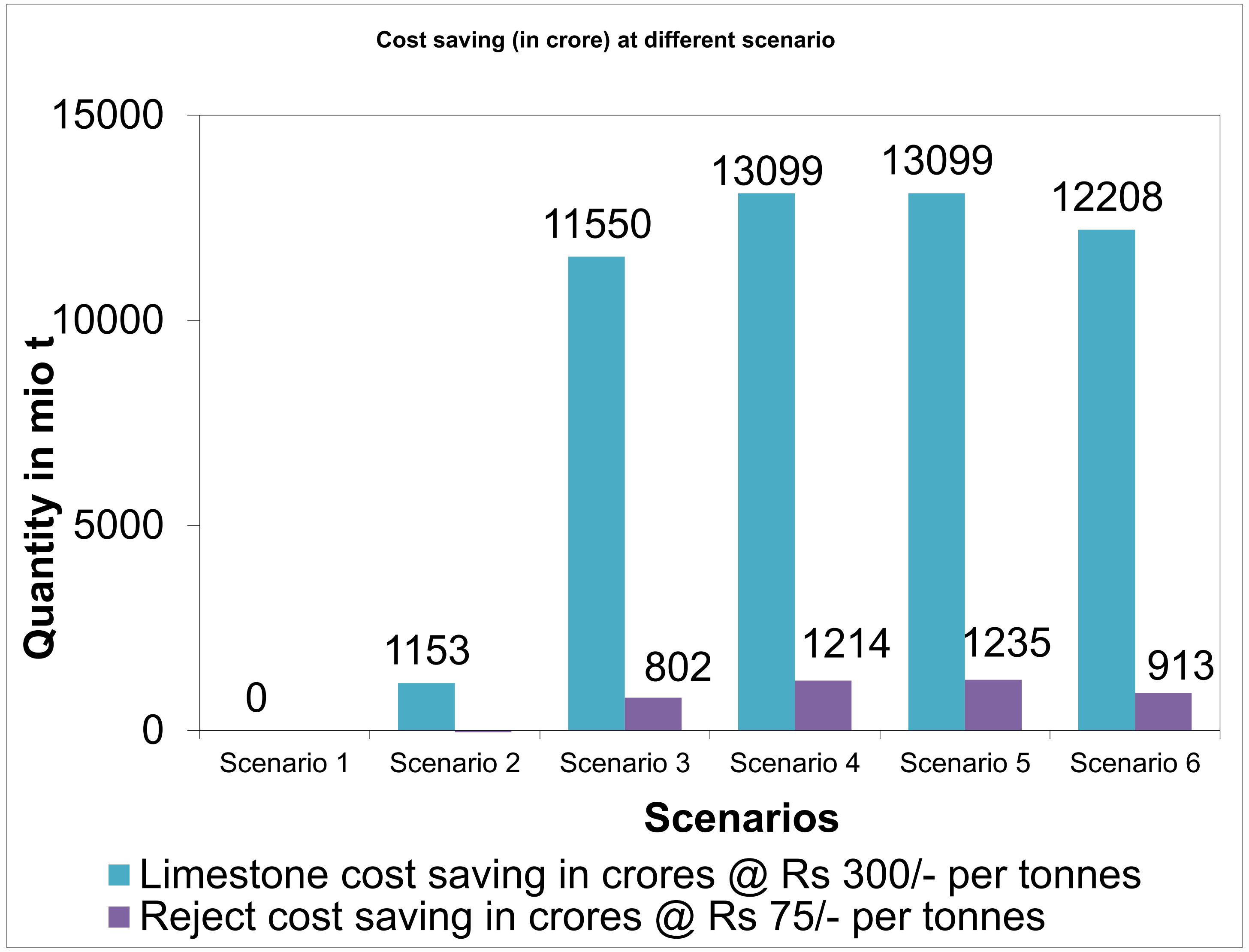
Real-Time Update Frequency

BENEFIT

	Quarry Monitoring	Long Term
Benefit Mining Engineer	➢ Quick and alternate solution ➢ Flexibility in operation ➢ Timely and Detailed analysis ➢ Avoid human biases	➢ Efficient operation management
Manager	➢ Evaluation of Multiple Scenarios ➢ Elimination of dedicated manpower	➢ Optimal use of deposit ➢ Streamlined quarry layout ➢ Continuous updation of inventory ➢ Better control over deposit
Company	➢ Saving in operating cost ➢ Continuous updation of inventory	➢ Enhanced equipment life/ uptime ➢ Enhanced Deposit Life

COST ANALYSIS – CASE 1 (INDIA)

Scenarios	Limestone			Rejects			
	Reserves	Reserves Increased by (mio t)	Cost saving crores @ Rs 300/- per tonnes	Rejects	Rejects Decrease (mio t)	Cost saving crores @ Rs 75/- per tonnes	Total Cost Saving (Rs in crores)
Scenario 1	94.91	-	0	195			0
Scenario 2	133.35	38.44	1153	233	-39	-291	863
Scenario 3	479.92	385.01	11550	88	107	802	12352
Scenario 4	531.54	436.63	13099	33	162	1214	14313
Scenario 5	531.54	436.63	13099	30	165	1235	14334
Scenario 6	501.83	406.92	12208	73	122	913	13121

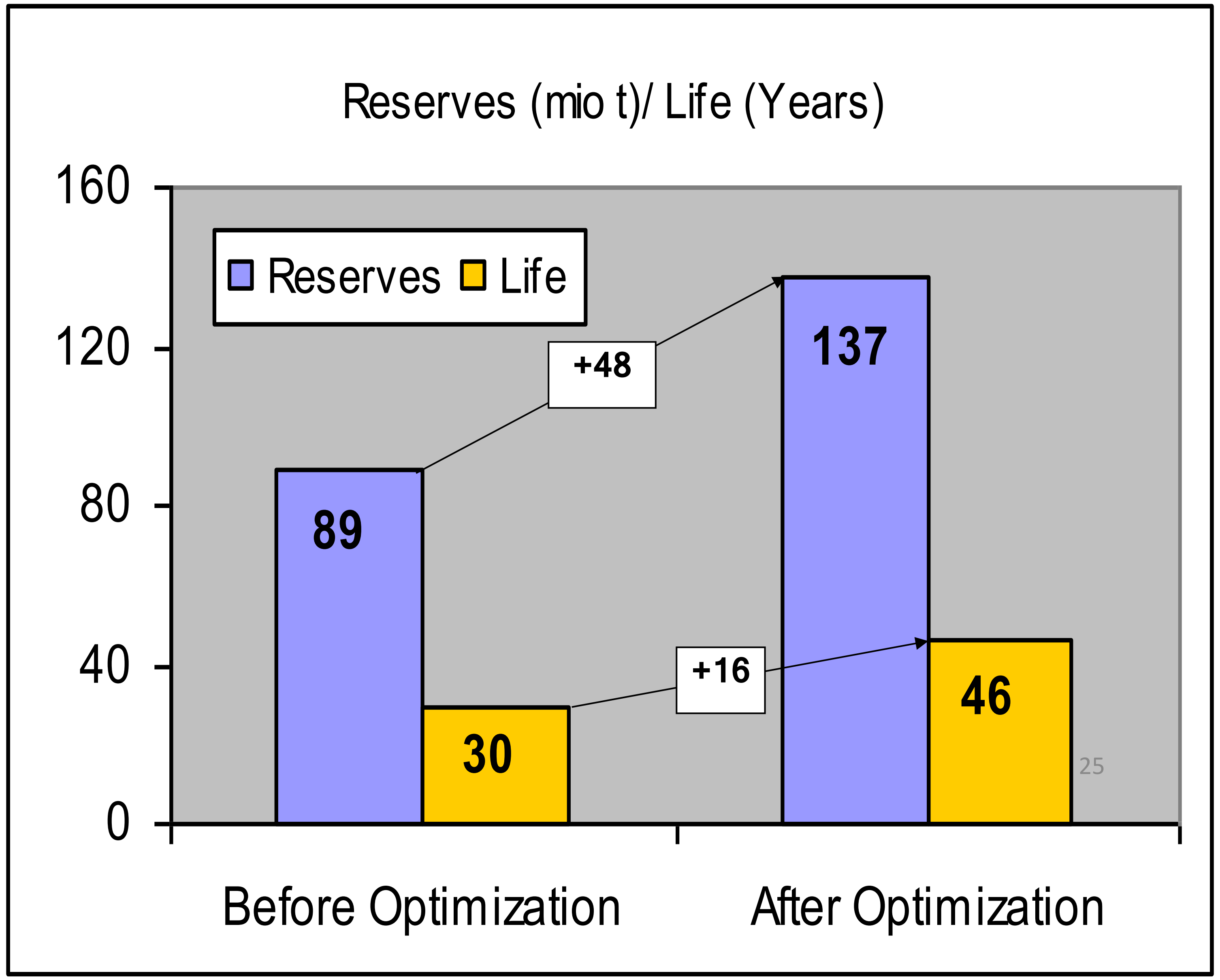


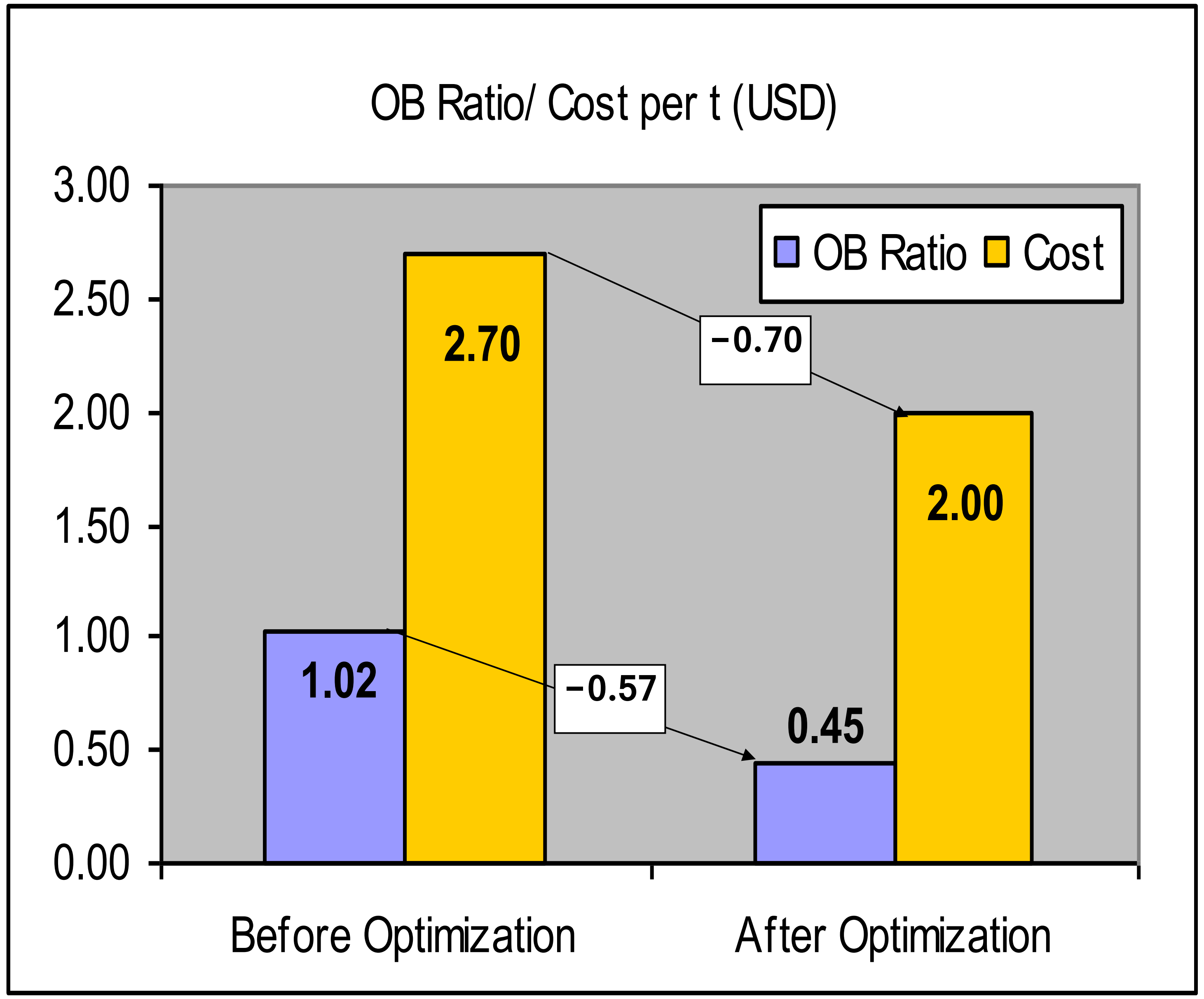
Reserves and costing with respect to existing raw mix

- The scenario 1, existing raw mix with laterite and LSF 103, SR 2.19, AR 1.11
- In scenario 2, with existing raw mix with use of iron ore, the cost saving is **Rs 863 crores**.
- In scenario 3, with recommended raw mix-1 CaO 42.10, LSF 109.68, SR 2.5, AR 1.35, the cost saving is **Rs 12,352 crores**.
- In scenario 4, with Recommended Raw mix-2 CaO 40.92, LSF 103, SR 2.5, AR 1.38 the cost saving is **Rs 14,313 crores**.
- In scenario 5, with Raw mix with LSF 103, SR 2.6 AR 1.45 and CaO 41.01 the total cost saving is **Rs 14,334 crores**.
- In scenario 6, with Raw mix with LSF 108.93, SR 2.6, AR 1.01 with Iron Ore the cost saving is **Rs 13,121 crores**

Reserves Enhancement with change in raw mix and reducing stripping ratio due to converting rejects into reserves resulting in to reduction in mining cost.

COST ANALYSIS – CASE 2 (SOUTH AFRICA)

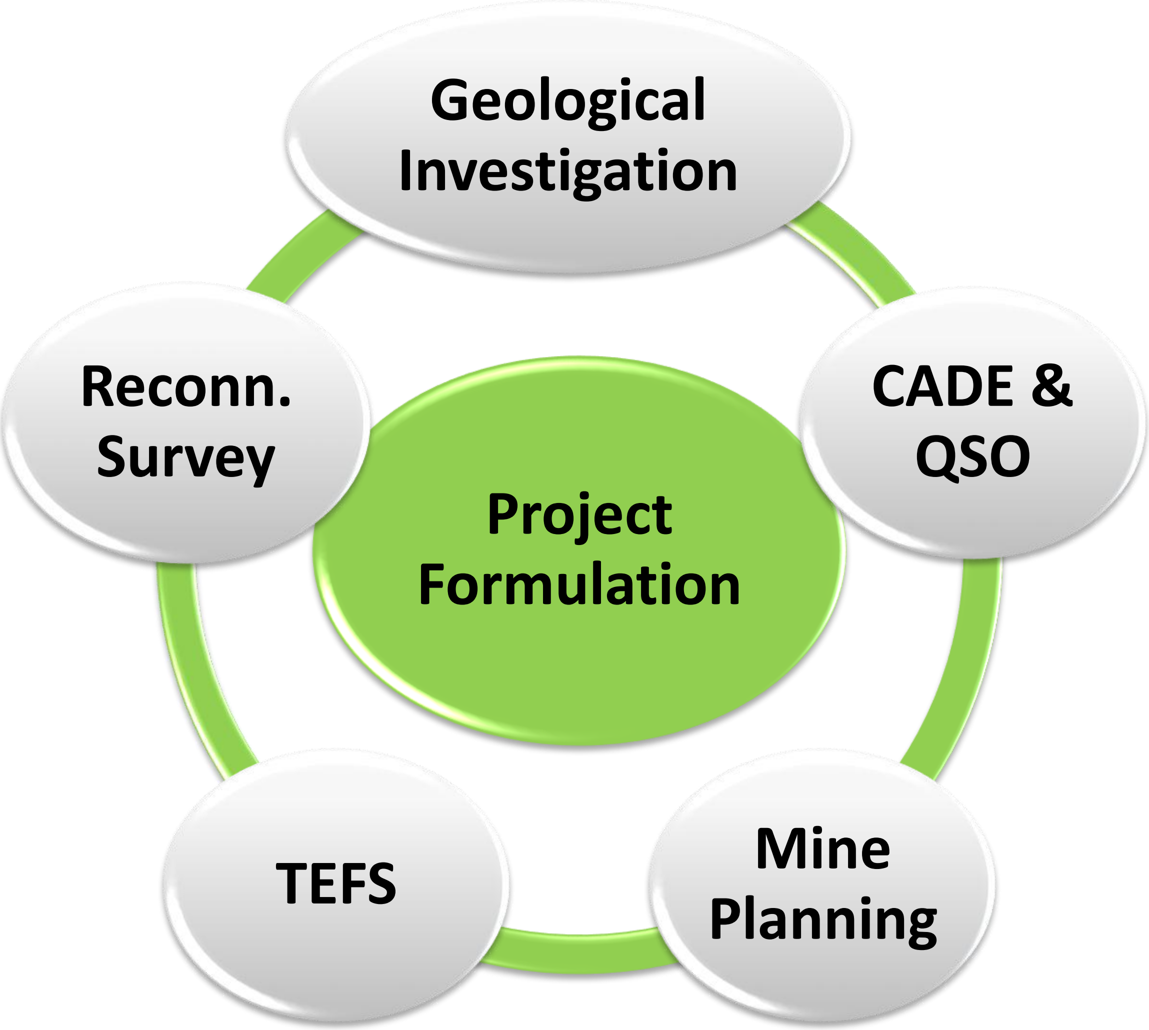


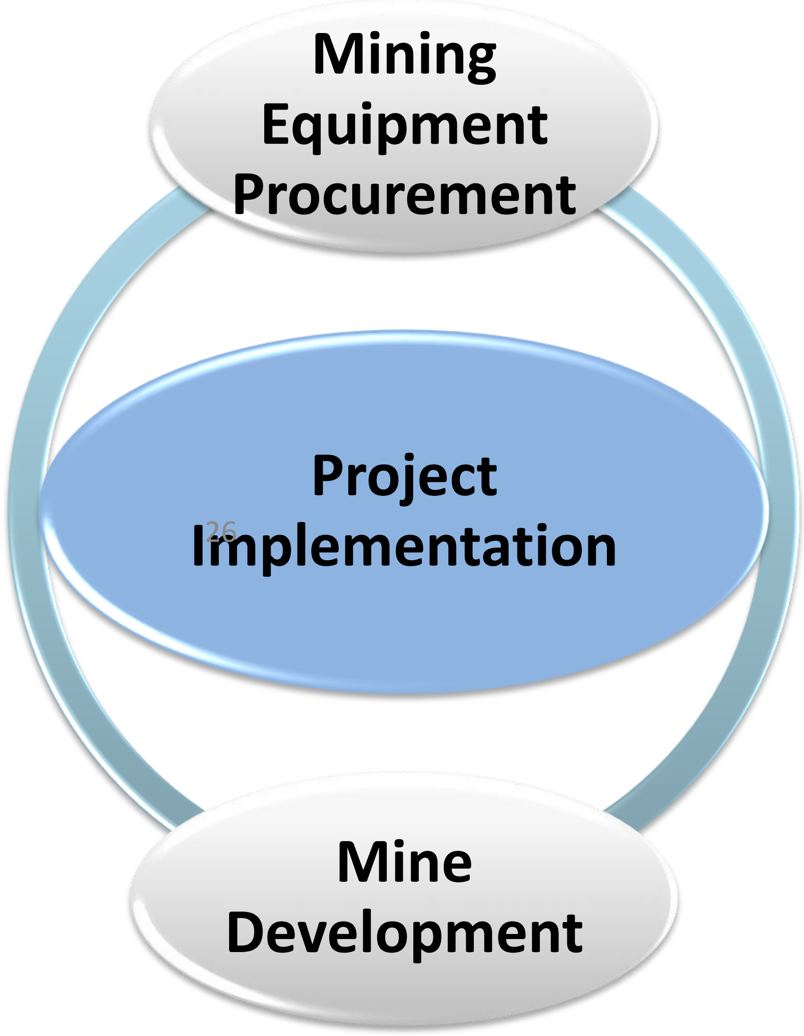


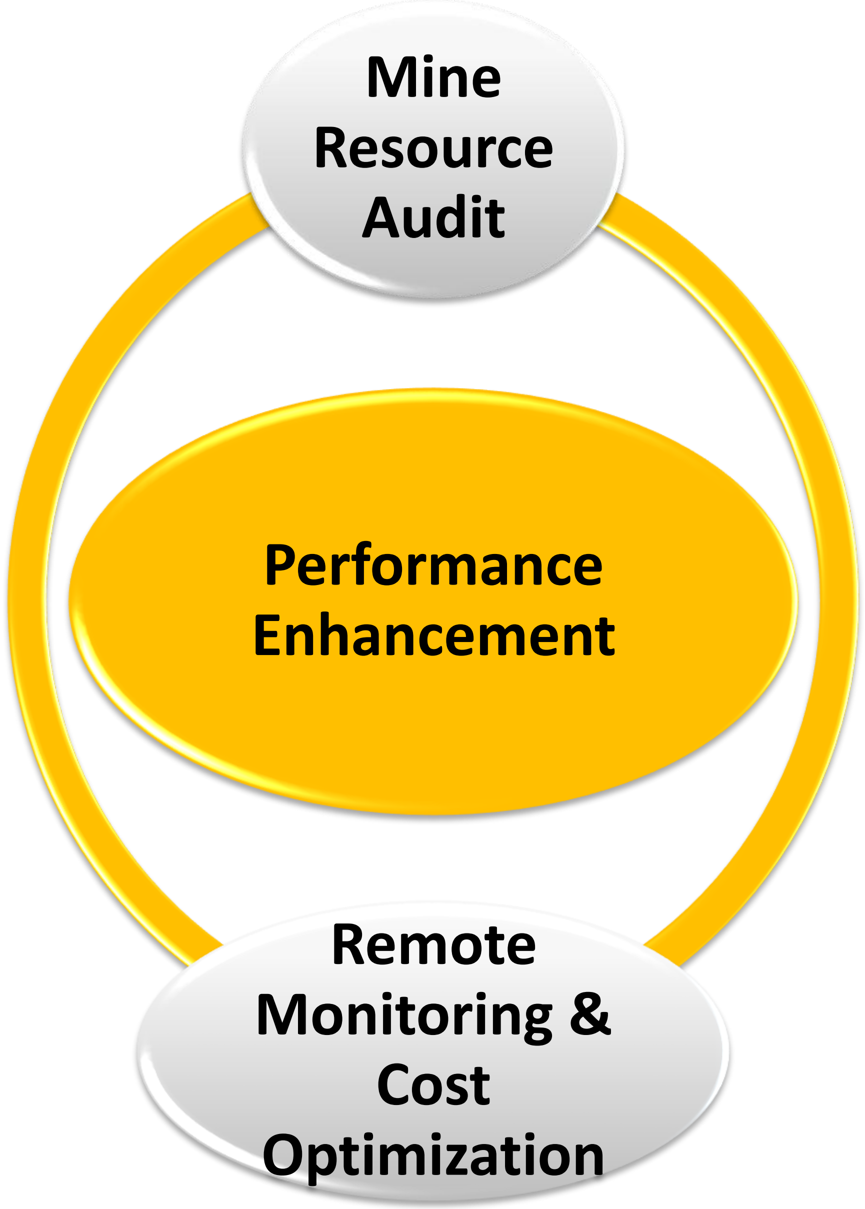
By model validation and rescheduling there is a saving of approx. 2.10 mio USD per annum just by reduction in reject. The additional life further adds to the saving over additional 16 years.

RAWMATERIAL SERVICES

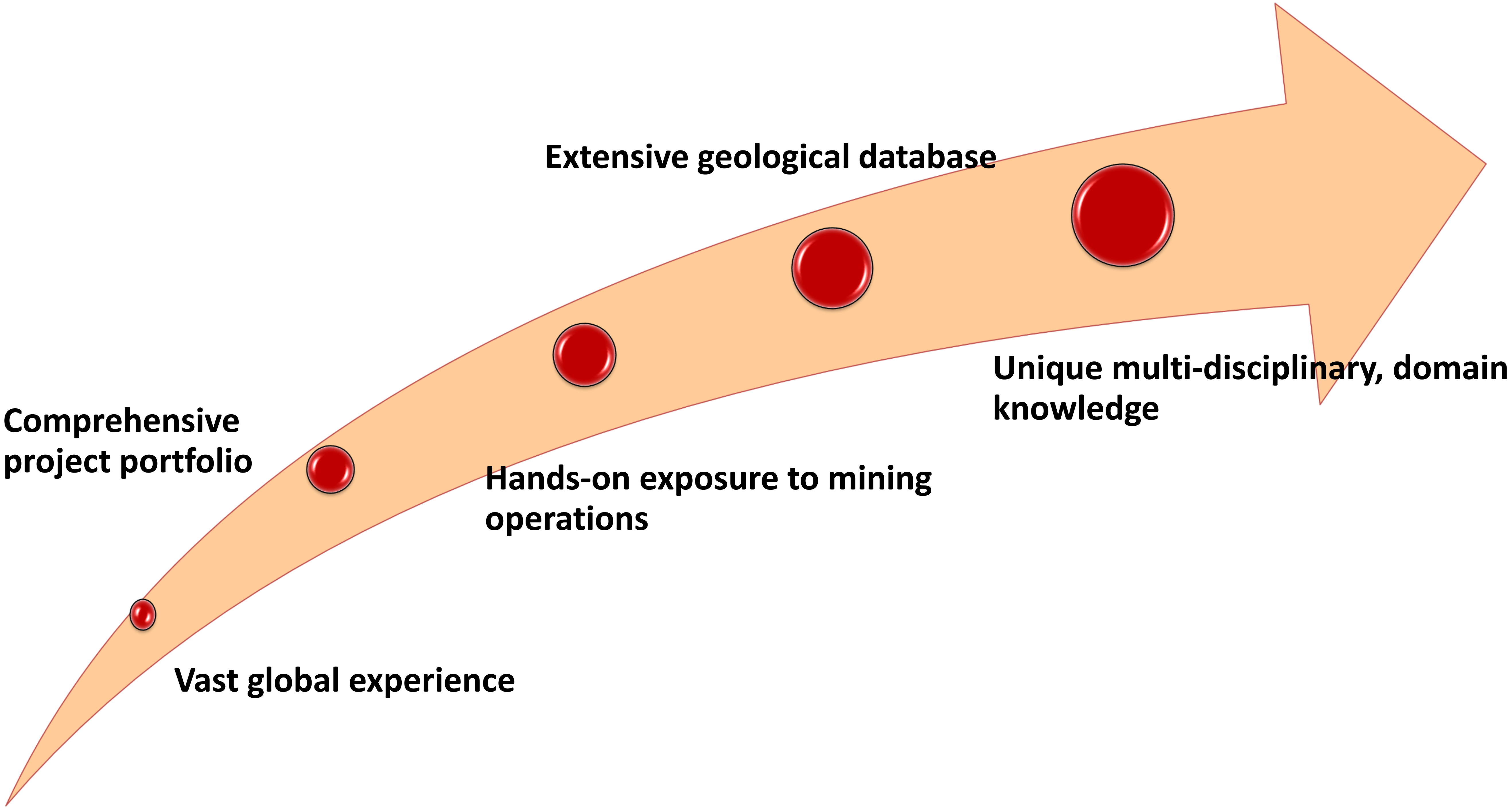
TEFS – Techno Economic Feasibility Study
CADE – Computer Aided Deposit Evaluation
QSO – Quarry Scheduling & Optimization







RAW MATERIAL SERVICES – HOLTEC's USPs



- Rich global consulting experience in > 750 assignments
- Customized Mine Optimization Software

THANK YOU

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