Truck Trolley System

Albrecht Brodkorb

26.8.2014

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Truck trolley in operation

Truck Trolley System
Main Subsystems – Overview

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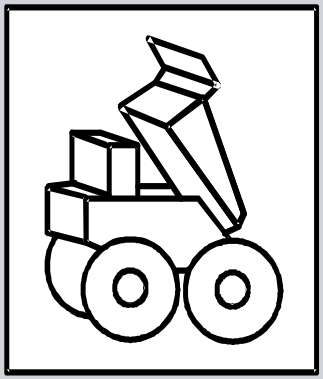
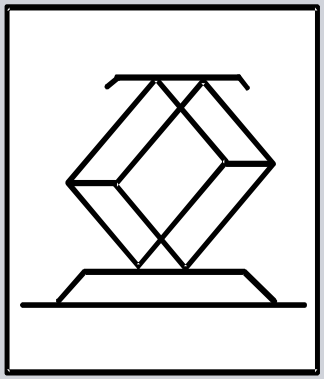
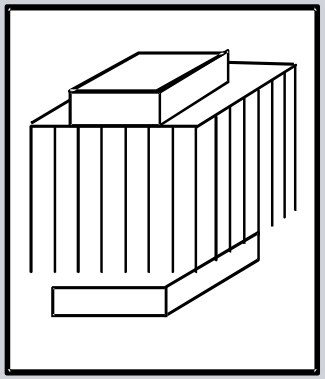
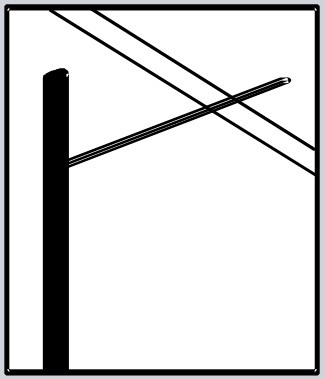

- Modification of trucks enabling them to operate under trolley
- Truck equipment with pantograph and pantograph sensor system
- Substation
- Overhead catenary system

Truck Trolley System
Basic concept

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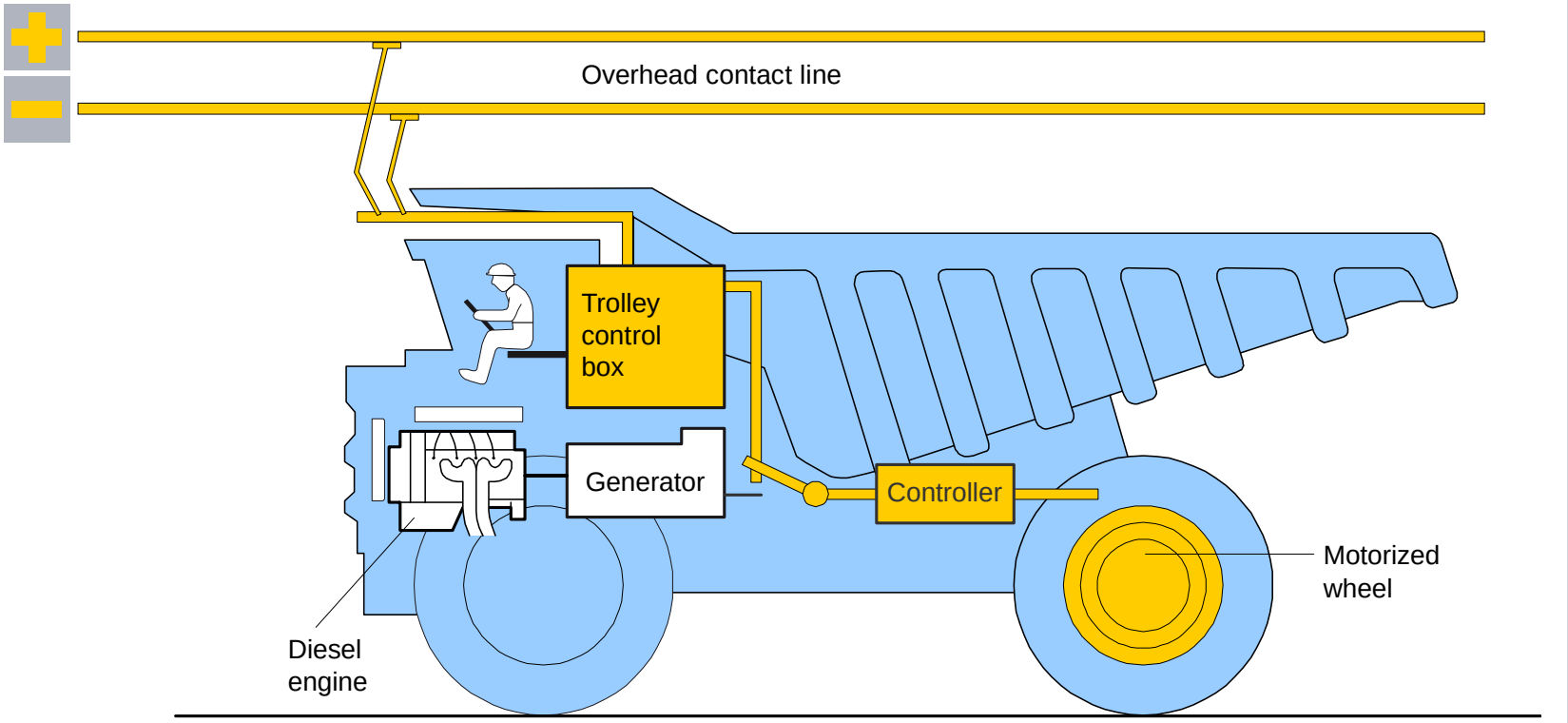
- The power is collected from a DC overhead line by means of 2 pantographs.
- Additional control devices apply the correct power to the motorized wheels



Truck Trolley System
Overhead Catenary System

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Two conductors are necessary

Each conductor is formed as an catenary, supported using poles and cantilevers positioned max. 40 m apart.

Typically with two contact wires and one/two messenger wires per catenary.

All wires are automatic tensioned. The mechanical tension of the contact wires and the messenger wires is
12 kN / 10 kN per wire.

Truck Trolley System
Feeding Substation

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Medium Voltage 3 Phase connection 6..30 kV.

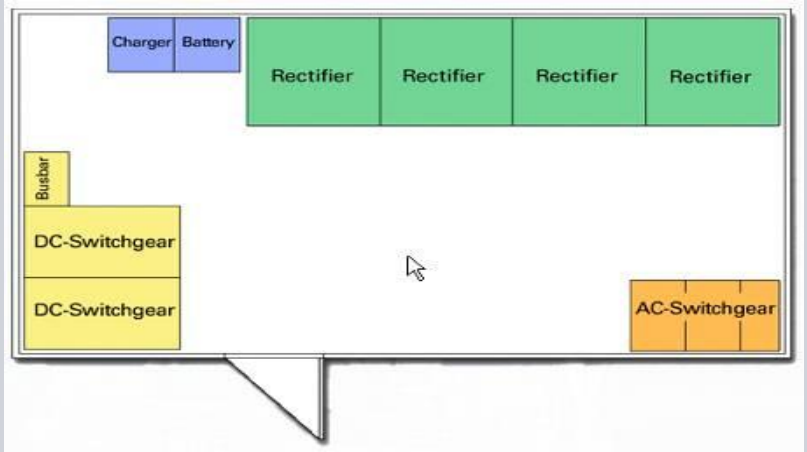
Power per substation 2,5 … 10 MW

Feeding range 0,8 .. 2 km

The nominal voltage of the trolley system and the power per substation depend on the specific operating conditions at the mine.

All equipment, except transformer, is protected from dust and moisture, housed in an air-conditioned, hermetically sealed container

Equipment is delivered mostly pre-installed and ready for commissioning.



Truck Trolley System
Pantograph Sensor System I – Components

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The pantograph sensor system ensures that the truck operates safely under the contact wire and that there is no damage to the overhead line. It consists of

- the sensor strips
- a box for electronic components
- the display

Sensor strips:

The sensor strips are inserted into the aluminium pipe, which is mounted on the pantograph.

Truck Trolley System Benefits

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Reduced operating costs

- Energy cost savings
- Diesel engine overhaul cost savings

Increased productivity

- Increase in truck speed
- Shorter turn-around times

Easy maintainability

- Use of standard components
- Less heating of wheel motor

Environmental benefits

- Fuel savings of up to 30 %

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Economic Evaluation Examples

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Truck Trolley

Economic Benefits

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Truck Trolley – Example Swedish Conditions Budgetary Parameters

25.8.2014

Truck Trolley Systems for Open-Pit Mining

- Most economical on ramps, where most of the total energy is consumed.
- Normal case: trucks drive uphill at ramps with high gradient from loading point to unloading point.
- Trolley is only installed on the uphill lines. Downhill the benefits of fuel saving or increase in speed would be minimal.

Application Guidelines

Trolley Assist is worth considering if a mine has:

- **High differential between electrical power and diesel fuel price**
- **“Long” life of ramps**
- **Deep pit with long ramps**
- **Semi-permanent ramp network**
- **Well constructed and maintained haul roads**

Contact line installation - 1

Contact line installation – 2

Substation installation

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Commissioning

Truck Trolley
Standard climate and design parameters

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• Ambient temperature range	min/max Temp = 5°C .. + 50°C
• Maximum wire temperature	90°C
• Ice layer on structures (masts, cantilevers)	No ice
• Wind speed for structural design	20 m/s
• Wind speed for conductor blow off	20 m/s
• Minimum Wind speed for thermal calculation of wire load capacity	0,6 m/s
• Minimum radius	120 m
• Max. operational speed	30 km/h
• Nominal voltage	1500 V DC acc. to EN 50163
• Feeding voltage	1800 V (U_{max1} acc. EN 50163)

!! needs to be adjusted for use in Sweden

Truck Trolley System
Optimum Support in all Project Phases

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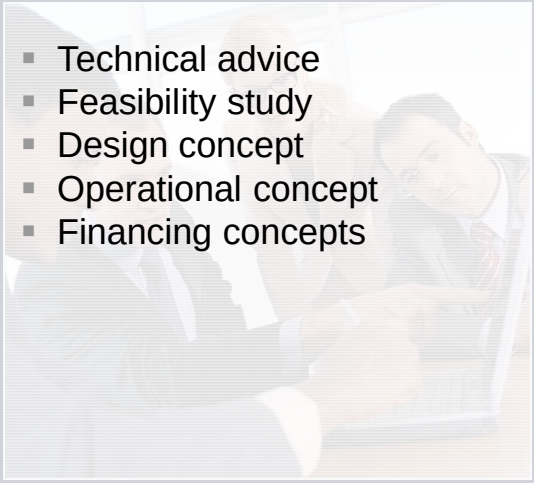

- Technical advice
- Feasibility study
- Design concept
- Operational concept
- Financing concepts

- Electrical and mechanical equipment
- Civil works
- Installation, commissioning, system integration tests, training, acceptance and approval

- After-sales
- Maintenance
- Operation
- System extension

Pre-award → **Implementation** → **Post-completion**

Consulting and system design

System engineering, project and interface management

Maintenance and extensions

Truck Trolley System
References – Overview

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USA
Barrick Goldstrike Mine

Democratic Republic of Congo
Gécamines

Zambia
Lumwana

Namibia
Rössing Mine Company

South Africa
Palabora Mining Company

Truck Trolley System References – Details

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Customer, Country	Route Length	Voltage	Substation Rating	Number of Substations	Total Converted Trucks	Commi-ssioning	Project Scope
Lumwana Mining Company, Zambia	4.0 km	2,400 V	10.0 MVA	5	27	2009	Catenary system and substations
Barrick Goldstrike Mine, USA	5.5 km	1,500 V	6.5 MVA	7	11	1994	Catenary system and substations
Gécamines, Democratic Republic of Congo	3.5 km	1,200 V	2.4 MVA	4	22	1986/89	Turnkey project
Rössing Mine Company, Namibia	8.5 km	1,200 V	3.0 MVA	5	30	1986	Catenary system and substations
Palabora Mining Company, South Africa	8.0 km	1,200 V	5.0 MVA	7	80	1981	Catenary system and substations

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Multi truck operation

Truck Trolley System
Thank You for Your Attention

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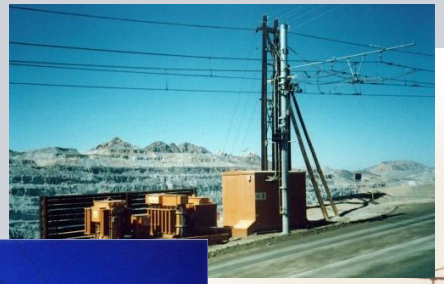

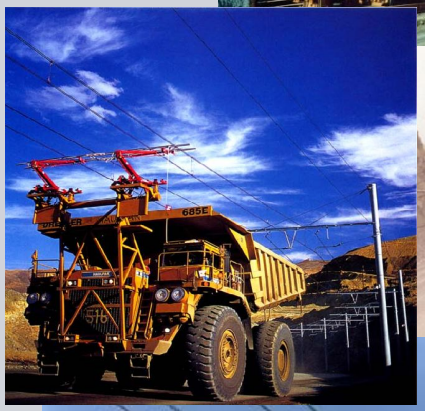

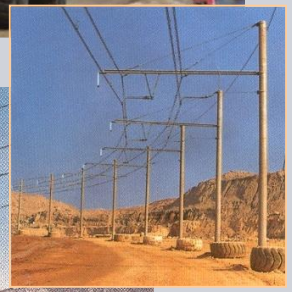

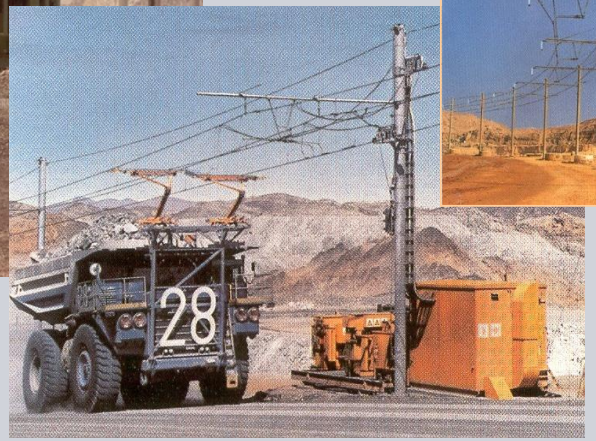

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Truck Trolley – Example Swedish Conditions Budgetary Parameters

25.8.2014

Truck Trolley
Economic Effects

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Additional Investment

- Fixed installation for Power supply
- Upgrade of trucks for Trolley-Assist

Benefits in Operation

- Shorter round trip time by higher speed under load conditions with trolley assist
- Increased haulage capacity per truck, usable for
  - → Reduced no. of trucks for same haulage target
  - → Increase haulage of the pit with same no. of trucks
- Reduced Maintenance for Diesel Engine
- Difference in Energy costs

Other Effects

- Change in CO2 footprint, depending from source of E-Energy
- use of regenerative energy

→ Economic evaluation has to cover all different influences for a specific case

Swedish Budget Conditions Example
Line Parameters

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Line parameters

Section	Length m	Grade	Trolley loaded	Trolley empty
1	300	0,0%	0	0
2	750	8,0%	0	0
3	1000	8,0%	1	0
4	3000	0,0%	1	0
5	100	-8,0%	0	0
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
Total length	5150		4000	0
		(sign for loaded drive)		

Swedish Budget Conditions Example
Truck parameters

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Truck data

Truck type	320 ton			
Empty weight	257	t		
Total weight with load	570	t		
Rolling resistance	0,02			
Auxiliary power	50	kW		
Wheel motor rating	4561	kW	power per hour	
	unit		Diesel	Electro
Max. speed loaded	km/h		50	50
Max. speed empty	km/h		50	50
Power of diesel engine	kW		2536	at flywheel
Power of control unit	kW			3875
Effectivity traction unit			0,898	
Effectivity of truck				0,898
Effectivity of OCL/SST				0,85
spec. fuel consumption	g / kWh		206	
Recuperation	0	0 -> no	1 -> yes	
Availability	94	%		
Exploitation rate	89	%		

Swedish Budget Conditions Example
Economic input - 1

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Energy price level

Diesel per l	9,00	SEK
El per kWh	0,308	SEK

Staff (driver)

Driver per Truck	3	
Yearly cost per driver	460,000	1000 SEK

Truck costs

Price per Diesel-Truck	46000	1000 SEK	per truck
Modification per Truck	3700	1000 SEK	per truck

Truck Maintenance

		Interval of rep	Cost of repair	Downtime
		h	SEK	h / repair
Diesel motor		250	116000	8
El. motor	Mode Diesel	2000	46000	8
	Mode Trolley	1800	46000	8

Swedish Budget Conditions Example
Economic input - 2

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Cost of fixed installation				
Substation				
	power per substation		7,5	MW
	unit price		9200	1000 SEK
OCL	price / km		14000	1000 SEK
Total price electrification				1000 SEK
			(Inputvalue=0 -> calculated from amount)	
Number of substations		5	(Inputvalue=-1 -> calculated from load)	
Benefit off additional haulage			40	SEK / t
CO2 Emmision Coefficient			combined incl. Manuf./Transport	
	Diesel		3,13	kg/l
	Electricity		0	kg/kWh
	Energy content diesel		9,88	kWh/l

Swedish Budget Conditions Example
Specific Results

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			Original	Truck-Trolley	Difference
Cycle times					
	driving time	min	26,32	24,20	-8,04%
	duration of a round trip	min	34,32	32,20	-6,17%
Cost for energy per cycle					
	Diesel	SEK	1063,14	445,19	
	Electricity	SEK	0,00	100,24	
	Energy per round	SEK	1063,14	545,43	-48,70%
Greenhouse-Gas Emission					
	Diesel	(CO2/haulage) kg/t	1,18	0,49	
	Electricity	(CO2/haulage) kg/t	0,00	0,00	
	Total	(CO2/haulage) kg/t	1,18	0,49	-58,13%
Haulage Capacity per truck					
	max. haulage per hour	t/h	547,2	583,2	6,57%
	Daily haulage (practical)	t/d	10071,1	10733,1	6,57%
Electrification data					
			Original	Truck-Trolley	
	Length of OCL	m	0	4000	
	Number of substations		0	5	

Swedish Budget Conditions Example
Specific Results for target haulage capacity

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Calculation for fixed haulage capacity

Yearly haulage (planned)	18,3	Mt		
		Original	Truck-Trolley	Difference
number of trucks		6	5	-16,67%
Yearly haulage (Status)	Mt	22,1	19,6	-11,19%
Specific costs				
Energy	SEK / t	3,40	1,74	-48,70%
Maintenance	SEK / t	1,29	0,70	-45,31%
Staff (driver)	SEK / t	0,45	0,38	-16,67%
Total operation	SEK / t	5,14	2,82	-45,02%
Return of additional Investment	2,14	Years		

Swedish Budget Conditions Example
Specific results for fixed truck usage

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Calculation for fixed number of trucks

number of trucks 5 (Installation see above)

		Original	Truck-Trolley	Difference
Yearly haulage (Status)	Mt	18,4	19,6	6,57%
Specific costs				
Energy	SEK / t	3,71	1,90	-48,70%
Maintenance	SEK / t	1,06	0,66	-38,42%
Staff (driver)	SEK / t	0,38	0,35	-6,17%
Total operation	SEK / t	5,14	2,91	-43,47%
Total incl capital costs	SEK / t	6,40	4,70	-26,55%

Swedish Budget Conditions Example
Monetary effects for defined mining capacity

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Calculation of armortisation for a fixed haulage capacity

Investment		Original	Truck-Trolley	
number of trucks		6	5	
Trucks	1000 SEK	276000	248500	
Fixed installation (power su	1000 SEK		102000	
OCL	1000 SEK		56000	0--> only total price
SST	1000 SEK		46000	0--> only total price
Total	1000 SEK	276000	350500	
Cost for Modification	1000 SEK		74500	
Yearly capital cost	1000 SEK	27600	35050	
Annual cost (Planned yearly haulage)				Savings
Energy	1000 SEK	61988	31802	**30186**
Maintenance	1000 SEK	23464	12832	**10631**
Staff (driver)	1000 SEK	8280	6900	**1380**
Total operation	1000 SEK	93732	51534	**42197**
Total incl capital costs	1000 SEK	121332	86584	**34747**
Savings for operation and capital				
	1000 SEK		34747	
Return of additional Investment	**2,14**	Years		

Swedish Budget Conditions Example
Monetary effects for fixed truck usage

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Calculation of cost for a fixed number of trucks				
	Increase of Haulage capacity		6,57%	
Investment		Original	Truck-Trolley	
	number of trucks	5	5	
Trucks	1000 SEK	230000	248500	
Fixed installation (power su	1000 SEK		102000	
OCL	1000 SEK		56000	
SST	1000 SEK		46000	
Total	1000 SEK	230000	350500	
Cost for Modification	1000 SEK		120500	
Yearly capital cost	1000 SEK	23000	35050	
Annual cost (Planned yearly haulage)				Savings
Energy	1000 SEK	68104	37236	**30868**
Maintenance	1000 SEK	19553	12832	**6721**
Staff (driver)	1000 SEK	6900	6900	**0**
Total operation	1000 SEK	94557	56969	**37588**
Total incl capital costs	1000 SEK	117557	92019	**25538**
Savings for operation and capital				
	1000 SEK		25538	
Return of additional Investment	Basis		Costs	Benefit
	SEK / t		5,14	40
Additional earnings by increased Haulage	1000 SEK		**6215**	**48325**
Return of additional Investment	Years		**3,795**	**1,631**

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Truck Trolley

Economic Benefits

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Truck Trolley
Economic Effects

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Additional Investment

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- Upgrade of trucks for Trolley-Assist

Benefits in Operation

- Shorter round trip time by higher speed under load conditions with trolley assist
- Increased haulage capacity per truck, usable for
  - → Reduced no. of trucks for same haulage target
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- Reduced Maintenance for Diesel Engine
- Difference in Energy costs

Other Effects

- Change in CO2 footprint, depending from source of E-Energy
- use of regenerative energy

→ Economic evaluation has to cover all different influences for a specific case

Truck Trolley – Sample Mine calculation
Basic data

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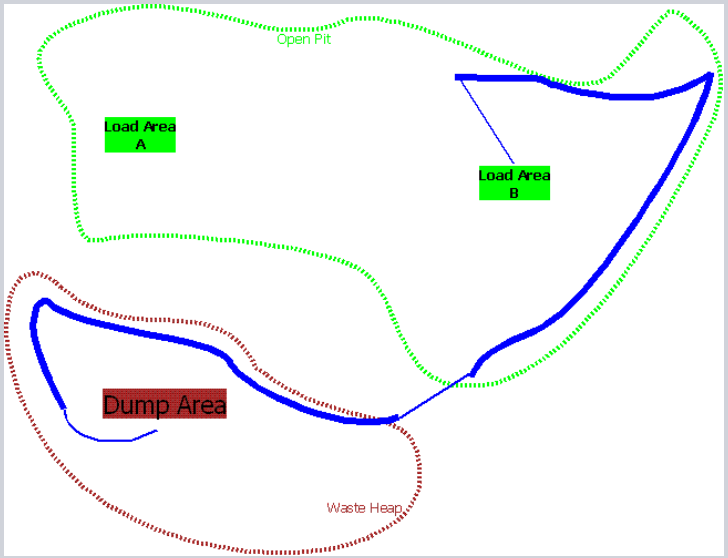
- 2 loading areas A and B
- Common dumping area on waste heap
- All ramps with constant gradient (Bold lines)
- For Truck Trolley operation all ramps are electrified
- Load / dump time : 5/2 minutes



Line parameter example load area B to dump area

Section	Length	Grade	Trolley
	m		loaded
1	300	0,0%	0
2	500	0,0%	0
3	1500	10,0%	1
4	100	0,0%	0
5	1500	10,0%	1
6	500	0,0%	0

Truck Trolley – Sample Mine calculation
Technical truck parameters used for the samples

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Truck type	550 t Sample truck – loading capacity 310 t			
Empty weight		240	t	
Total weight with load		550	t	
Rolling resistance		0,02		
Auxiliary power		55	kW	
Wheel motor rating		4000	kW	power per hour

	unit	Diesel	Electro	
Max. speed loaded	km/h	50	50	
Max. speed empty	km/h	35	35	
Power of diesel engine	kW	2400		at flywheel
Power of control unit	kW		5100	
Effectivity traction unit		0,89		
Effectivity of truck			0,898	
spec. fuel consumption	g / kWh	220		

Truck Trolley – Sample Mine
Main economic data used for samples *

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Energy price level

Diesel per l	0,90	USD
El per kWh	0,077	USD

Truck costs

Price per Diesel-Truck	5000	1000 USD
Modification per Truck	500	1000 USD

Cost of fixed installation

Substation unit price	1400	1000 USD
OCL price / km	2000	1000 USD

CO_2 Emission Coefficient

Electricity	0,2	kg COx / kWh

Further Input parameters

Maintenance costs

Additional Benefits for increased capacity

* All economic values are fictive values for this samples without relation to a specific mine

Truck Trolley – Sample Mine
Effects for a single round trip (B → waste heap)

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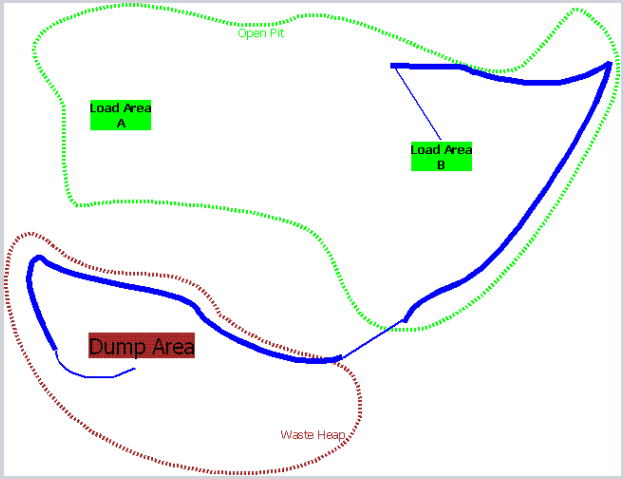
Capacity effects

		Diesel mode	Truck-Trolley	Difference
Duration of a round trip	min	37,06	29,64	-20,01%
Cost for energy per cycle	USD	160,72	67,54	-57,98%
Haulage Capacity per truck	t/h	501,9	627,5	25,02%



Truck Trolley – Sample Mine
Effects for a single round trip (B → waste heap)

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Results for a required haulage capacity of 20,1 Mt/year

		Diesel mode	Truck-Trolley	Difference
Necessary number of trucks		7	5	
Investment	1000 USD	35000	41900	
Specific costs				
Energy	USD / t	0,52	0,22	-57,98%
Operation	USD / t	0,69	0,32	-53,18%
Annual costs				
Energy	1000 USD	10408	4374	-6034
Total operation costs	1000 USD	13844	6482	-7362
Total incl. capital costs *	1000 USD	17344	10672	-6672

Return of additional Investment **1,03 Years ***

* Capital costs for an interest rate of 10%

Truck Trolley – Sample Mine
Effects for a single round trip (B → waste heap)

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Results for a fixed number of 5 trucks

		Diesel mode	Truck-Trolley	Difference
Haulage capacity	Mt/year	16,5	20,6	25,02%
Investment	1000 USD	25000	41900	
Specific costs				
Energy	USD / t	0,52	0,22	-57,98%
Operation	USD / t	0,67	0,32	-52,02%
Greenhouse-Gas Emission				
Total (CO2/haulage)	kg/t	1,80	0,61	-66,07%
Annual costs				
Energy	1000 USD	8548	4491	-4058
Total operation costs	1000 USD	11003	6599	-4403
Total incl. capital costs*	1000 USD	13503	10789	-2713

* Capital costs for an interest rate of 10%

Return of additional Investment **3,09 Years**

0,72 Years (with a benefit of 5 USD per t additional haulage)

Truck Trolley – Sample Mine
Conjoint use of Routes

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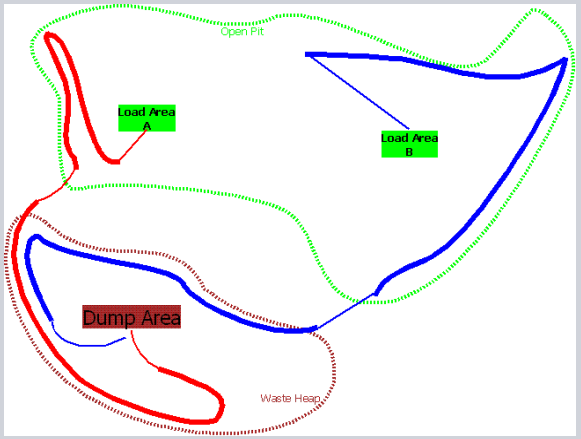
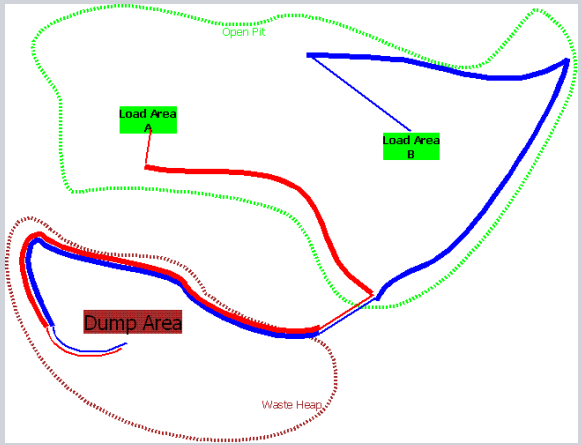
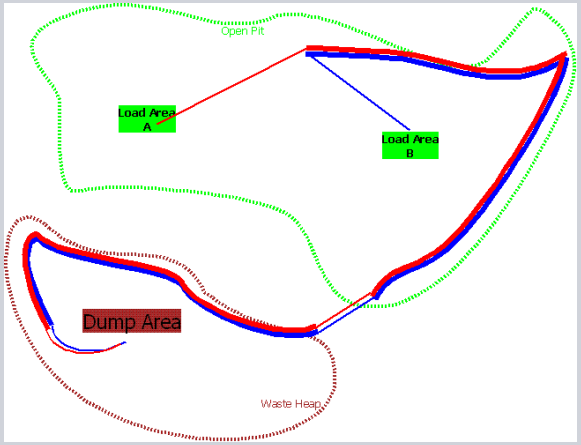
- 2 loading areas A and B
- Common dumping area on waste heap



Separate Ways
A_B



Partial sharing
A1_B



Common used ways
A2_B

Truck Trolley – Sample Mine
Conjoint use of Routes

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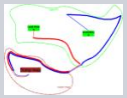
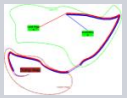
Amortisation time for 10 trucks with different route bundling

		separate ways	partial sharing	common_used
Route		**A + B**	**A1 + B**	**A2 + B**
				
Total trip length	km	16,200	12,400	10,400
OCS	km	6,000	4,500	3,000
Substation		12	9	6
Number of Trucks		10	10	10
haulage capacity	t/h	1301	1301	1255
Invest Truck Trolley	1000 USD	30600	26400	19400
Yearly energy savings with Truck Trolley	1000 USD	8404	8404	8116
Yearly savings with Truck Trolley	1000 USD	9135	9135	8806
Return on Invest *	**Years**	**5,04**	**4,06**	**2,83**

* Capital costs for an interest rate of 10%

Truck Trolley – Sample Mine
Usage of route

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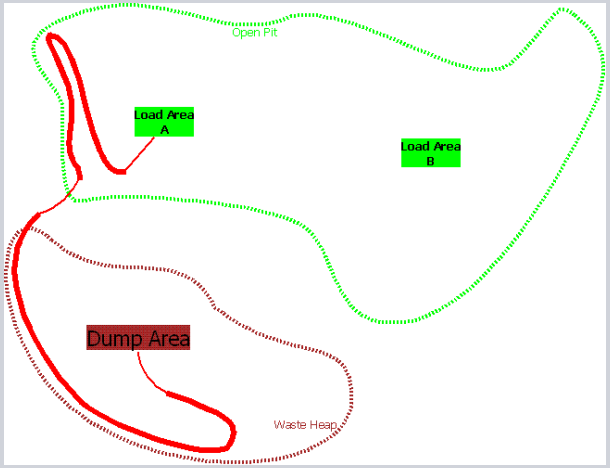
Route from loading area A to dump area



Line parameters load area a to dump area

Section	Length m	Grade %	Trolley loaded
1	300	0	
2	1500	10	1
3	100	0	
4	1500	10	1
5	300	0	

Calculation of same route for use with 3, 5 and 10 trucks

Truck Trolley – Sample Mine
Usage of route

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Amortisation for route A as function of number of Trucks

Number of Trucks		3	5	10
Haulage capacity Diesel Trucks	Mt / year	10,5	17,4	34,9
Haulage capacity Truck Trolley	Mt / year	13,3	22,1	44,3
Investment Truck Trolley	1000 USD	12700	13700	16200
Yearly energy savings with Truck Trolley	1000 USD	2607	4346	8691
Yearly savings by Truck Trolley	1000 USD	2839	4732	9463
Return on Invest *	**Years**	**8,09**	**4,07**	**2,07**

* Capital costs for an interest rate of 10%

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Thank you for your attention