Underground haulage selection: Shaft or ramp for a small-scale underground mine

by B. Elevli*, A. Demirci*, and O. Dayi†

Synopsis

This paper deals with the selection of alternative accesses to a podiform chromite orebody in Turkey. The most important alternatives studied in a related project have been stated as a new vertical shaft and a ramp system. The comparison of these alternatives have been carried out on the basis of total investment costs, ore transport unit cost and net present value (NPV) of overall project for various depth. The results show that up to the depth of 700 m, the total investment cost and NPV favours the ramp access while unit ore transport cost make the shaft access preferable.

Introduction

One of the stages of underground mining operations is to transport extracted ore to the stockpile or processing plant located on surface that is known as haulage system. In spite of existence of different haulage systems, the skip hoist/shaft haulage system has been the most widely utilized system for an orebody that lies far below the starting point of access. For a long time this system has been the cheapest way to transport ore from underground to the surface. However, due to the latest technological developments in underground diesel/electric trucks have resulted a change in mine haulage systems. Ramp haulage system, if applicable, has become a new alternative to the shaft system for some underground operations. As a result, a number of mines have adopted ramp haulage system for transporting ore (Nilson[1]). For example, two-thirds of Australia's underground mines have chosen a ramp-truck haulage system (Chadwick[2]).

These situations force the mine managers to compare the skip/shaft hoist and ramp-truck haulage systems for their existing and potential operations. One of these mines is Pinarbasi chromite mine, which has to compare various alternative accesses and transportation technologies in Turkey. The comparison must be made on the basis of generally acceptable criteria. Some of these criteria are:

- Total development and equipment investment amount of transportation system
- Ore transport cost
- Net Present Value (NPV) of overall project.

In order to compare alternative transportation systems with each other, the objective values of each alternative must be estimated on the basis of every relevant criterion. In this case the manager may be able to make a decision, which may be considered as rational and justifiable.

Within the scope of this study, a technical-economical comparison was made between shaft hoist and ramp haulage system equipped with underground diesel truck for the mine mentioned above. Following chapters deal with the description of the mine, mining methods and alternatives to be incorporated into evaluations.

Mine description

The mine operation subject to this study is a small-scale mine producing about 60 000 tons/year of chromite ores coming from two separate ore lenses being excavated by means of underground mining. In general the production policy of the mine bases on explore-discover-extract activities. In this way of mining, exploration drill holes have been drilled from a selected level to 100 m downward (Figure 1). Based on the results of this exploration work, orebody is developed and extracted. Then, the above steps are to be repeated for another 100 m slice before the reserve of previous slice delineated. The main disadvantage of this policy is management's inability for long-term planning and the risk of costly mining activities.

* *C.U. Mining Engineering Department, Sivas, Turkey.*

† *Chief Mining Engineer, Dedeman PinarbasiMadencilik, Kayseri, Turkey.*

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The extracted ore is transported to surface via shaft hoist that had initially designed based on the ore depth of approximately 120 m down from the surface, later on this shaft was deepened to a depth of -220 m. Recent exploration studies and geological information have shown that the orebody might extend down to 500 metres. In this case, the existing hoist shaft will be inadequate to transport extracted ore since it was not designed for this depth. Therefore the mine management decided to have a study comparing different alternatives for the transport of the ore lying in lower parts of the orebody. This comparison may be based on an assumption that the orebody might extend up to a depth of 700 m.

Current mining method

The current mining method is a modified top-slicing with filling. In this method the ore is extracted in form of slices from the top downward. In order to implement this method, firstly the main haulage levels as part of developments are driven from the shaft to the orebody at 30 m intervals whereby these developments are directed to the centre of the orebody. As these developments approach to the ore contact zone, nearly 10 m apart, other further development drifts are driven parallel to the ore-rock contact in each main level. Several haulage cuts are driven from this development drift to the orebody at 30 m apart. These haulage cuts are connected by raises which serve as ore passes and connections between main levels also. As the haulage cuts enter the ore, the tramming drift is driven generally parallel to the contact zone. If the ore is sufficiently thick this drift has to be centred horizontally in the slice. The tramming drifts are timbered and form the basis for the start of slicing operations. They are also connected to the raises. The ore is extracted by driving a series of drifts nearly at right angle to the tramming drift until to the limit of the orebody. These drifts are timbered using three-piece sets. The excavation of ore is carried out with drilling and blasting. The blasted ore is mucked to the ore passes by an LHD having a capacity of 0.4 m^3. The ore in the ore passes is discharged into 0.7 m^3 mine cars which are driven to the shaft using manpower. After driving and timbering the drift the floor is covered with round timber poles. Afterwards the opening is filled with filling material brought in from the surface. As this operation is carried out, the other production drivings are set to continue further extraction operations. After the first slice has been extracted fully the next underlying slice is began to be excavated.

Hoist shaft alternative

If hoist shaft alternative is chosen as an access to the underground, the required hoisting rate must be at least 60000 tons ore/year plus minor quantities of development waste. In addition to that, shaft will also be used for material and labour transportation. In order to guarantee the required transportation rate, the hoist speed is to be 2.3 m/sec and size of shaft has to be 3.4 m $\times$ 2.4 m = 8.16 m^2. There must be main haulage levels for each 30 m interval. The size of main haulage levels is planned to be in the range of B8 for the first 30 metres away from the shaft and B5 for the rest of the drift. The mining method will be as given above.

In order to evaluate the hoist shaft alternative, first the required amount of development work must be estimated. Therefore, the shaft and other development plans are drawn by using VULCAN software. The 3-D view of development plan is given in Figure 1. Based on this drawing, the amount of required development is placed on Table I.

The shaft sinking is to be made by means of drilling and blasting. The advance rate will be 0,8 m per day. For the muck removal, hand mucking will be used. The muck removal in the first 10 m of main haulage levels will also be made by using muck bucket. After that, the hoist will be used to remove muck of further parts of drifts.

For the hoist shaft transport system, the total development from the start of preparation to full mine production (up to the level of -310) requires approximately 2 years. After the level of -310, the development will be driven step by step, and each time the shaft sinking will be 90 metres. During the shaft sinking, the production has to be ceased. Each sinking takes approximately one year.

After estimating the required development work, the detailed and total development cost needs to be estimated. The development costs for each target depth are given in Table II (Demirci[3]).

As it can be seen in Table II that the total development cost increases from $450 000 for the level of -220 m to $3,5M for the level of -700 m. The ore transport cost is

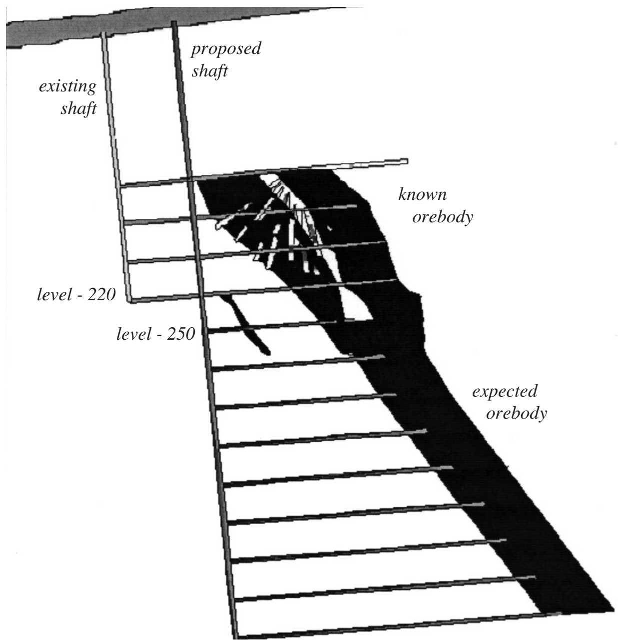

Figure 1—The 3-D view of shaft hoist alternative

Table I

The total required development

Levels	-250	-280	-310	-400	-490	-580	-670	-760
Shaft (m)	255	285	315	405	495	585	675	765
B8 Drift (m)	30	60	90	180	270	360	450	540
B5 Drift (m)	108	234.4	379.2	924	1634	2510	3552	4759
Ramp access (m)	204	408	612	1224	1836	2448	3060	3672

Table II

Shaft alternative development costs

				Levels				
Required development (m)	**-250**	**-280**	**-310**	**-400**	**-490**	**-580**	**-670**	**-700**
Shaft*	255	285	315	405	495	585	675	705
B8-Bucket	10	10	10	10	10	10	10	10
B8-Normal	20	20	20	20	20	20	20	20
B5-Normal	110	131	152	215	278	341	404	425
Drift (m)	100	100	100	100	100	100	100	100
Cumulative drift (m)	100	200	300	600	900	1200	1500	1600
Shaft Sinking Cost ($/m)								
Drilling-Blasting	112.34	112.34	112.34	112.34	112.34	112.34	112.34	112.34
Loading-Hauling	29.63	30.62	31.60	34.54	37.49	40.43	43.38	44.36
Ground Support	241.92	241.92	241.92	241.92	241.92	241.92	241.92	241.92
Vent. and Drainage	20.81	21.91	23.06	25.71	29.76	34.45	39.88	41.88
Labour	630.51	630.51	630.51	649.57	679.24	710.27	742.71	753.85
Sub Total	1035.22	1037.30	1039.43	1064.09	1100.76	1139.42	1180.24	1194.36
G. expenses (%10)	103.52	103.73	103.94	106.41	110.08	113.94	118.02	119.44
TOTAL ($/m)	1138.74	1141.03	1143.38	1170.50	1210.83	1253.36	1298.26	1313.79
B8 Driving (with bucket)								
Drilling-Blasting	54.80	54.80	54.80	54.80	54.80	54.80	54.80	54.80
Loading-Hauling	12.55	13.33	14.11	16.45	18.79	21.13	23.47	24.25
Ground Support	27.47	27.47	27.47	27.47	27.47	27.47	27.47	27.47
Vent. and Drainage	20.81	21.91	23.06	25.71	29.76	34.45	39.88	41.88
Labour	480.54	480.54	480.54	480.54	480.54	480.54	480.54	480.54
Sub Total	575.37	576.15	576.93	579.27	581.60	583.94	586.28	587.06
G. expenses (%10)	57.54	57.61	57.69	57.93	58.16	58.39	58.63	58.71
TOTAL ($/m)	655.79	657.86	659.98	665.47	672.50	680.24	688.78	691.84
B8 Driving (Normal)								
Loading-Hauling	9.68	10.12	10.55	11.84	13.13	14.43	15.72	16.15
TOTAL ($/m)	652.64	654.06	656.06	660.40	666.28	672.86	680.26	682.93
B5 Driving								
Drilling-Blasting	40.14	40.14	40.14	40.14	40.14	40.14	40.14	40.14
Loading-Hauling	5.89	6.04	6.18	6.61	7.04	7.47	7.90	8.04
Ground Support	15.02	15.02	15.02	15.02	15.02	15.02	15.02	15.02
Vent. and Drainage	5.62	5.92	6.23	6.94	8.04	9.30	10.77	11.31
Labour	156.55	156.55	156.55	156.55	156.55	156.55	156.55	156.55
Sub Total	223.21	223.65	224.11	225.25	226.78	228.47	230.37	231.05
G. expenses (%10)	22.32	22.37	22.41	22.53	22.68	22.85	23.04	23.11
Total ($/m)	245.53	246.02	246.52	247.78	249.45	251.32	253.41	254.16
Total development cost								
Shaft Sinking	284.686	318.917	353.218	457.416	565.167	676.678	792.158	831.572
B8-driving with bucket	6.558	13.101	19.662	39.425	59.353	79.471	99.803	106.632
B8-driving	13.053	26.139	39.260	78.786	118.643	158.879	199.543	213.202
B5-driving	27.009	59.237	96.708	240.659	432.570	673.252	963.626	1.071.642
B5-Drift	24.553	49.155	73.807	147.999	222.663	297.868	373.676	399.091
Ramp for LHD	50.089	100.375	150.869	303.279	457.997	615.230	775.421	829.563
Prep. and equipments	44.000							
TOPLAM (x1000 $)	450	611	778	1.312	1.900	2.545	3.248	3.496

calculated on the basis of 60000 tons per annum. The cost includes both fix costs such as amortization and interest, and variable costs such as materials and labour as given in Table III.

As it can be seen in Table III, the ore transport unit cost decreases from the level of -250 m to the level of -310 m, then it starts to increase again. Main reason for that is the changing amortization of shaft and hoist accessories depending on increase in reserve with depth.

Ramp alternatives

If ramp alternative is chosen as an access to underground, the extracted ore will be hauled to surface by means of underground trucks. In this case, required development work will include ramp from one main level to another level and a directional horizontal drift for each level. The access to each slice will be from the ramp. LHD will load the extracted ore to the truck at each slice. The size of the ramp has to be B6.3 and the size of drift has to be B5. The ramp and other development plans are drawn by using VULCAN software. The 3-D view of development plan is given in Figure 2. Based on this drawing, the amount of required development is given in Table IV.

The investment for the required development is estimated on the basis of cost calculation in related project (Demirci[3]). The results are shown in Table V.

For the ramp system, the development from the start of preparation to full mine production (up to the level of -250 m) requires approximately 2 years. After that, the ramp development is to continue the production since it will provide filling material. That means at the selection of ramp alternative the production will not cease any further.

Table III

Ore transport cost in case of shaft hoist

Levels	250	280	310	400	490	580	670	700
Amort. of shaft and hoist accessories (investment/10 year)	9.00	6.11	5.18	4.37	4.22	4.24	4.33	4.37
Interest	0.90	0.92	1.04	1.53	2.11	2.76	3.46	3.71
Sub total	9.90	7.03	6.22	5.90	6.33	7.00	7.80	8.08
Energy	0.13	0.15	0.16	0.19	0.23	0.26	0.29	0.31
Rope (increases with depth in practice)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Maintenance of main levels	0.10	0.06	0.09	0.20	0.33	0.48	0.65	0.72
Maintenance of shaft and accessories (%20 of amort)	0.13	0.19	0.22	0.32	0.43	0.53	0.64	0.68
Rail cost	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Labour	3.05	3.05	3.05	3.14	3.28	3.43	3.59	3.64
Sub-total	3.61	3.64	3.71	4.05	4.47	4.91	5.38	5.55
Total	13.51	10.66	9.93	9.96	10.80	11.91	13.18	13.63
Unexpected cCost (%7)	0.95	0.75	0.70	0.70	0.76	0.83	0.92	0.95
Total ($/ton)	14.45	11.41	10.63	10.65	11.56	12.74	14.10	14.58

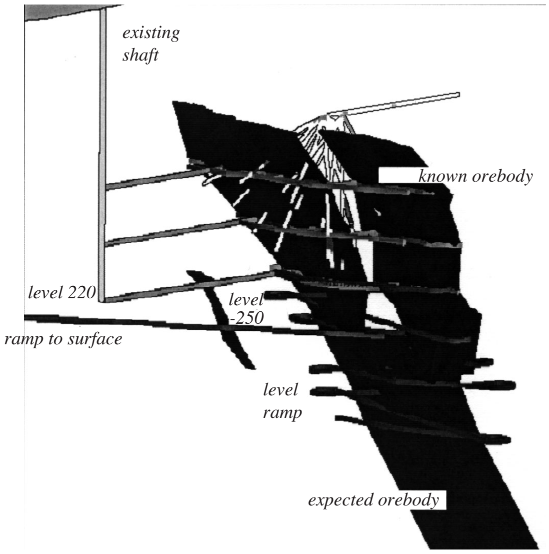

Figure 2—3-D plan view of proposed ramp access

Table IV

The required development for ramp access

Levels	-250	-280	-310	-400	-490	-580	-670	-700
Main ramp (surface to -250L)	1603	1603	1603	1603	1603	1603	1603	1603
Main level drifts (m)		100	200	500	800	1100	1400	1500
Ramps from level to level (m)		204	408	1020	1632	2244	2856	3060
Curves (m)		67.5	135	337.5	540	742.5	945	1012.5
Total	1603	1974.5	2346	3460.5	4575	5689.5	6804	7175.5

Table V

Investment cost for ramp alternative

Levels	-250	-280	-310	-400	-490	-580	-670	-700
B6.3 DRIFT								
Drilling-Blasting	37.10	37.10	37.10	37.10	37.10	37.10	37.10	37.10
Loading-Hauling*	48.40	48.40	48.40	48.40	48.40	48.40	48.40	48.40
Ground Support	48.64	48.64	48.64	48.64	48.64	48.64	48.64	48.64
Vent. and Drainage	4.92	4.63	4.77	5.22	5.70	6.23	6.81	7.01
Labour	86.36	86.36	86.36	86.36	86.36	86.36	86.36	86.36
Sub-total	225.42	225.13	225.27	225.72	226.20	226.73	227.31	227.51
Unexpected (%10)	22.54	22.51	22.53	22.57	22.62	22.67	22.73	22.75
TOTAL ($/m)	247.96	247.64	247.80	248.29	248.82	249.40	250.04	250.26
B5 DRIFT								
Drilling-Blasting	40.14	40.14	40.14	40.14	40.14	40.14	40.14	40.14
Loading-Hauling*	52.25	52.25	52.25	52.25	52.25	52.25	52.25	52.25
Ground Support	15.02	15.02	15.02	15.02	15.02	15.02	15.02	15.02
Vent. and Drainage	5.62	5.92	6.23	6.94	8.04	9.30	10.77	11.31
Labour	124.68	124.68	124.68	124.68	124.68	124.68	124.68	124.68
Sub-total	237.70	237.99	238.31	239.02	240.12	241.38	242.85	243.39
Unexpected (%10)	23.77	23.80	23.83	23.90	24.01	24.14	24.28	24.34
TOTAL ($/m)	261.47	261.79	262.14	262.92	264.13	265.52	267.13	267.73
Cumulative cost								
LEVELS	-250	-280	-310	-400	-490	-580	-670	-700
Main Ramp ($)	397477	397477	397477	397477	397477	397477	397477	397477
Main Level Drifts ($)	0	50518	50550	50651	50759	50878	51008	51054
Curves ($)	0	16716	16726	16759	16795	16835	16878	16893
Ramp (level to level) ($)	0	26179	26214	26292	26413	26552	26713	26773
Truck ($)	163500		163500		163500			
TOTAL ($x1000)	561	654	911	1192	1474	1920	2203	2298

In order to compare both alternatives, the required production must be taken equal as 60 000 tons ore/year. Ore transport cost is estimated on the basis of this assumption. The estimated cost covers the cost of transporting of extracted ore from loading point to the stockpile at surface by means of underground trucks. The cost increases with depth as seen in Table VI.

As it can be seen in Table VI, the operating cost for truck haulage (with 6 tons diesel truck) is estimated to be between 9.76 $/ton and 16.34 $/ton for different levels. These figures include also the ownership cost of the trucks.

Comparison of alternatives

As stated in the above sections two alternative approaches to underground ore transport have been incorporated into the scope of this article. The comparison of these alternatives comprises both technical and economic parameters and criteria. In the original project several alternatives have been taken into consideration. The most preferable alternatives stated have been chosen to be compared on sustainable production over a period of 16 years whereby the development of shaft has to be carried out in 90 m intervals within every three years periods. On the other hand the development of the ramp is to be driven continuously after starting the full production.

The comparison of the alternatives on the basis of total fixed investment cost is given in Figure 3. This Figure is prepared on the basis of depth versus investment cost for development. According to Figure 3 the investment cost of shaft hoisting is lower than the investment cost of the ramp system up to the depth of -370 m level. After this depth the ramp alternative becomes preferable.

Figure 4 gives the comparison of alternatives on the basis of other criteria such as total cost, unit investment cost and unit operation cost. According to Figure 4, the total unit cost for ramp alternative is lower than the total unit cost of shaft hoisting up to the depth of -370 m level. After this depth, the total unit cost of shaft alternative is lower than the total unit cost of ramp alternative. The unit investment cost for ramp alternative is slightly lower than the unit investment cost of shaft alternative. Unit operating cost for both alternatives increases with depth linearly, but the slope of unit operating cost for ramp alternative is bigger than the slope of operating cost of shaft alternative. According to these results, after the depth of -370 m, the shaft alternative becomes preferable.

Another assessment is carried out on the basis of net present value calculations assuming cash inflows in the range of $1 800 000 per year. These calculations indicate NPV in the range of $7 785 000 for shaft hoisting and an NPV in the range of $9 309 000 for ramp system assuming a discount rate of 10 per cent. The latter alternative has a discounted cash flow advantage of $ 152 4000. The results step up the preferability for ramp system

Conclusions

This study has showed that an acceptable level of mechanization is possible for small-scale mines and

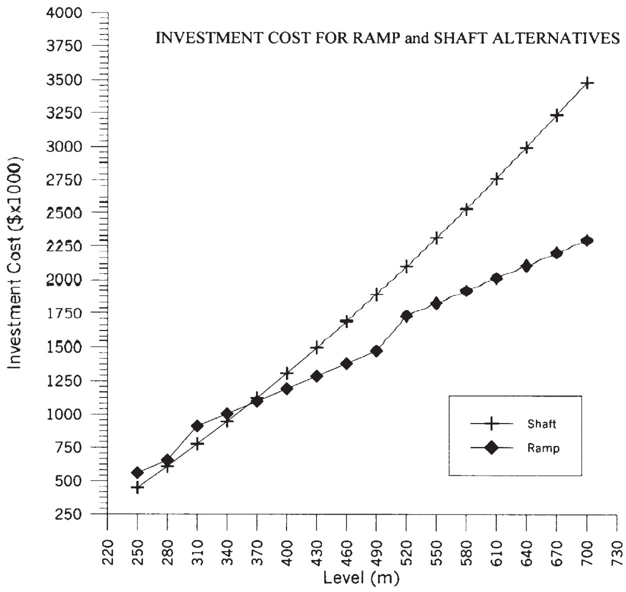

Figure 3—Comparison of investment cost

Table VI

Ore transport cost for ramp haulage

LEVELS		250	280	310	400	490	580	670	700
Ramp and	Amortization	7.95	4.91	4.99	3.43	2.92	2.93	2.72	2.67
Drifts	Interest	0.79	0.74	1.00	1.20	1.46	1.91	2.18	2.27
Underground	Amortization	0.47	0.55	0.62	0.85	1.08	1.30	1.53	1.60
Trucks	Interest	0.17	0.19	0.22	0.30	0.38	0.46	0.54	0.57
	Insurance	0.06	0.06	0.07	0.10	0.13	0.15	0.18	0.19
Sub-total		9.44	6.45	6.90	5.88	5.95	6.75	7.15	7.30
Maintenance of ramp and drifts (15% of amort.)		0.12	0.15	0.18	0.26	0.34	0.48	0.56	0.59
Underground	Fuel-Oil	0.49	0.57	0.65	0.88	1.12	1.35	1.59	1.66
Trucks	Maintenance	0.64	0.74	0.84	1.14	1.45	1.76	2.06	2.16
	Oil-Hyd., etc.	0.08	0.09	0.11	0.15	0.19	0.23	0.26	0.28
	Tires	0.14	0.17	0.19	0.26	0.33	0.40	0.47	0.49
	Tires Mainte.	0.04	0.05	0.06	0.08	0.10	0.12	0.14	0.15
Labour		0.78	0.90	1.02	1.39	1.76	2.14	2.51	2.63
Sub-total		2.30	2.67	3.04	4.16	5.28	6.46	7.59	7.96
Total		11.74	9.12	9.94	10.04	11.24	13.21	14.74	15.27
Unexpected Cost (%7)		0.82	0.64	0.70	0.70	0.79	0.92	1.03	1.07
TOTAL ($/ton)		12.56	9.76	10.64	10.74	12.02	14.14	15.77	16.34

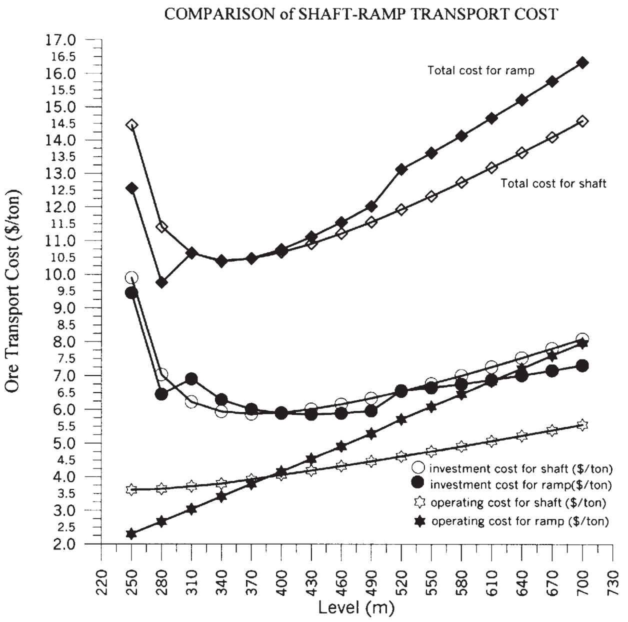

Figure 4—Comparison of ore transport cost

mechanization provides some advantages. In addition to that the utilization of underground trucks in mines advancing downwards with explore-discover-extract policy provides temporal solutions to some of the mining problems. The case study for this research provides a solution to the problems arising from the nature of indefinite reserve. The solution of such problems being considered as a selection problem can be searched on the basis of:

- Total investment cost
- Ore transport cost
- Net Present Value of project, and as well as multicriteria analysis carried out in original project (Demirci 2001).

The following conclusions can be drawn from this study.

- Total investment cost for shaft hoisting and ramp haulage increases almost linearly with depth. However, the slope of shaft hoisting is bigger than the slope of ramp haulage.
- Total ore transport cost for ramp is higher than the cost of shaft hoisting after the level of -370 m. This criterion indicates that the ramp haulage has a cost advantage over the shaft hoisting for upper levels in earlier depth. After the depth of 370 m, shaft hoisting becomes superior over the ramp haulage.
- Under the assumption that the reserve and production rate extends up to the depth of 700 m, an NPV analysis has been carried out. For this analysis the life of project is considered to be 21 years for shaft hoisting and 17 years for ramp haulage since the production has to be ceased for shaft sinking periodically. The results show that NPV for the ramp haulage is higher than the NPV of shaft hoisting alternative at 10 per cent discount rate. The related NPV values have a difference of 15 per cent.
- On the other hand the general approach to mining applications show that the near surface underground mines are better suitable to ramp systems. The calculations carried out in this study confirm approximately this point of view. Additional to that other criteria such as flexibility of system, selectivity and suitability for mechanization support such approaches in general.

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New global joint-venture marketing agreement*

LANGLEY, Canada—Following on the heels of the first ConSep ACACIA Reactor sale in North America, Knelson and Australian counterpart ConSep Pty have reached a global joint-venture marketing agreement for this new technology.

The ConSep ACACIA Reactor is a patented high efficiency gravity concentrate leaching system developed by Anglogold at their Union Reefs Gold Mine in northern Australia. Sydney-based ConSep Pty is the global manufacturer and distributor of the technology and is also the manufacturing licensee for Knelson Concentrators in Australia and the South Pacific.

'There is a lot of existing synergy between ourselves and ConSep which made this a very easy decision for us,' said Brett Knelson, VP of Business Development for Knelson.

'The ACACIA is clearly the most technologically advanced and proven system of its kind available, and when ConSep was granted the world-wide distribution, it was a natural fit for us,' added Knelson.

The ConSep ACACIA Reactor is the result of more than three years intensive in-field development at Union Reefs. The system was exclusively designed to handle the high-grade concentrates produced by Knelson Concentrators. Attempts to modify previously available systems to handle these concentrates have met with limited success.

Thus far six ConSep ACACIA Reactors have been sold, four of which are in operation and two that will be commissioned during the second quarter of 2002. In addition to Union Reefs these include: Sunrise Dam Gold Plant (Anglogold), Carosue Dam Gold Mine (Pacmin/Sons of Gwalia), Porgera Gold Mine (Placer Dome), Golden Giant Gold Mine (Newmont Canada) and How Gold Mine (Lonhro-Zimbabwe).

Knelson is located in Langley, British Columbia, Canada. The company provides unique processing solutions to the world. For additional information on Knelson and the products and services they offer, visit their website at www.knelson.com/mp/equipment/acacia.html. ◆

* *Contact: Doug Corsan, VP International Sales*
Tel: (604) 888-4015, E-mail: micaelallen@knelson.com